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MONTHLY WEATHER REVIEW

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LIGHTNING INVESTIGATION AS APPLIED TO THE AIRPLANE [1]

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While the lightning hazard to airplanes or any aircraft is very small compared to many everyday risks, this hazard receives much attention. Although lightning has caused a few fatalities, it would seem that many cases of trouble due to other causes have been unjustly charged to lightning. Once the effect of lightning upon the pilot or plane is recognized, steps can be taken to materially reduce if not eliminate the hazard, although this may be small at most.

The studies made in the high voltage laboratory of the Ohio Insulator Co. for Ward T. Van Orman in testing out his protection for free balloonists, and the series of tests run on planes and other equipment furnished by Popular Mechanics, provide some rather interesting information. An attempt will be made to cover some of these studies briefly.

Since the tests run in connection with free balloons illustrate certain phases of the subject to better advantage than those upon airplanes, this matter will be treated first.

In running the series of tests balloon baskets, small size balloons, model airplanes as well as full sizes air planes were placed between a large electrostatic condenser and ground on the test field. The condenser may be regarded as a charged cloud and a discharge taking place between this cloud and ground can be made to strike the equipment under test. Figure 1 shows a discharge taking place from this condenser to ground, the photograph being taken by a synchronized camera.[2]

In general the hazards from lightning may be divided into two classes:

(A) Electrical or physical shock, which may affect the pilot and passengers.

(B) Those hazards which damage the plane or aircraft.

It would seem that the hazard due to the direct electrical or physiological effect of lightning upon the pilot or passengers should receive first consideration, rather than the damage to the aircraft. Unfortunately it is very difficult to obtain information upon this point owing to the variation in the personal element itself, and the hazard of making studies which may be exceedingly dangerous. It may be said, however, that as the size of aircraft increases the direct danger to pilot or passengers tends to decrease providing ordinary precautions are taken in the design and construction of the aircraft. This is due to the greater distance of the crater or point of contact of the lightning from pilot and passengers.

Hazards to the plane or aircraft.—These hazards may be classified as follows:

1. Fire hazard due to ignition of combustible material used in the construction of the plane.
2. Fire hazard due to ignition of explosive gases.
3. Weakening or destruction of metal or other parts due to current in the discharge.
4. Breakdown of insulation in the ignition system.
5. Back fire or preignition.
6. Damage to instruments.
7. Damage to rotating parts due to passage of current.
8. Sudden change in pressure on adjacent surfaces.

Electrical or physiological shock to pilot or passengers.—The experience of free balloonists throws considerable light upon the hazard due to shock, and means of protection. The fatalities in Belgium and Pittsburgh of recent years caused Van Orman to give this matter considerable attention.

In the Pittsburgh race Van Orman's balloon was struck by lightning while at an altitude of 3,000 feet and set on fire, and Morton, who was with him in the basket, was killed by the stroke. The 26 R. C. A. portable loop radio set which was between Van Orman and Morton appeared to be badly damaged. However, an investigation showed that the set was not damaged electrically. Van Orman was apparently conscious for a short time after the stroke. He then lost consciousness and apparently remained in a stunned or dazed condition for five or six hours after the parachuting balloon struck ground.

Wollam and Cooper in the *City of Cleveland* had a somewhat similar experience, the stroke of lightning apparently passing over the surface of Cooper's leather jacket or suit which was wet at the time. The shunt path provided by the suit apparently saved Cooper's life, although he was badly burned by the stroke. Wollam escaped uninjured and attempted to lift Cooper and his parachute out of the basket, but was unable to do so. Cooper apparently is the only known person to suffer a heavy direct stroke and still live to tell about it.

These incidents show that a stroke of lightning may be very close to a person without causing any serious injury. Had the pilots been subject to the same condition while flying an airplane, it is possible that they might have lost control of the plane causing it to crash.

Figure 2 shows the basket used on the *City of Cleveland* balloon which was struck while the balloon was at least 5,000 feet in the air.

The photograph shows the basket with a dummy in place being subjected to an artificial lightning discharge. The steel cables from the ring to the basket were not bonded to the reinforcing wires which were used in making up the basket. It is possible that had bonding been carried out, the results might have been quite different.

In the tests shown in Figure 2, the collapse of the electrostatic field caused an induced potential of over 25,000 volts between the dummy and the lower part of the basket. While the energy is not large, the discharge might tend to frighten or startle one similar to a shock one receives in coming in contact with a metal object

[1] Communicated by W. T. Van Orman, Goodyear-Zeppelin Corporation, Akron, Ohio.

[2] All figures are grouped on inset sheets at end of article.—*Editor.*

after picking up a charge in walking over a carpet in cold dry weather.

Figure 3 (not reproduced) shows the metal reinforcing wire fused due to the discharge of lightning. It will be noticed that the horizontal wire crossing the vertical wire has been burned in two, as well as some of the basket material. An examination of the basket showed a large number of burns where the reinforcing wires crossed each other.

Figure 4 shows a test on Van Orman's lightning protecting scheme. The protection consists essentially of a cage formed by conductor hanging freely. These conductors are bonded at the top and part way down, but left entirely free at the bottom so as not to interfere with landing or parachute jumps from the basket. The conductors forming the shunt path are moved outward from the basket a short distance. The cable supporting the basket to the ring has been replaced with rope. It would seem that had this device been used in the flights in Belgium and Pittsburgh, the fatalities due to direct stroke would have been eliminated.

Apparently there is little difficulty in shunting the main discharge, but there is some question as to how far the discharge should be from the pilot so that he will not be stunned or frightened to the extent of losing control. The baskets in racing balloons are rather small, and anyone in the basket must of necessity be very close to any discharge striking the basket. Should the Van Orman cage give the necessary protection for direct hits, it would go to show that the protection to pilot or passengers in an airplane may be easily provided by shunting the discharge a short distance to one side.

Danger of direct hit.—Many people believe that a balloon or airplane should not be subjected to a lightning stroke while flying, since there is no direct ground connection. Any object which has a greater conductivity than the air or a greater electrostatic flux carrying capacity will tend to disturb the electrostatic field and will cause a discharge in the immediate vicinity to take a path along the object.

Effect of construction upon a stroke of lightning.—In running the tests on the Van Orman cage, an attempt was made to protect the balloon. If the gas in the balloon is free from air, lightning will not cause it to explode although the balloon may be set on fire. If an explosive mixture is present in the balloon, an explosion may take place due to the ignition of the mixture.

Difference between a wet and a dry balloon.—In the study of high voltage phenomena, particularly those applicable to transmission line structures using wood, it was believed that there would be a considerable difference between a wet and a dry balloon. The tests were very interesting in this connection, as they go to show that while there might be a considerable difference in aircraft which is constructed of metal and that primarily of nonconducting material, when dry there would be little difference where the latter was wet. This difference is undoubtedly due to the increase in electrostatic capacity due to the presence of water.

Figure 5 shows a hydrogen filled balloon being subjected to an artificial stroke of lightning. The balloon has a conductor attached approximating a long antenna, hanging from the lower side. A number of discharges were applied to the balloon similar to that in Figure 5. All of these discharges struck to the upper part of the conductor attached to the balloon, and then from the lower end of this conductor to ground.

As soon as the balloon was wet, however, conditions were entirely changed, the performance being similar to that shown in Figure 6. The discharges instead of going directly to the antenna and then to ground, struck the surface of the wet balloon. The discharge in Figure 6 is apparently passing along the surface, which destroyed the balloon in all cases. The discharge invariably burned the rubber and set the escaping gas on fire. Had the photograph been taken a fraction of a second later, the balloon would have been collapsed, the duration of the arc shown in the photograph being less than one half microsecond.

These tests go to show that there is little or nothing to be gained electrically by the use of nonconducting material in the aircraft structure where the material becomes wet, as the electrical fields set up are not materially different.

A discharge striking conducting material adjacent to inflammable material is likely to set the latter on fire. There are many cases which illustrate this point. Owing to the tendency of a discharge to strike a wet balloon, it was evident that it was necessary to remove the point of contact of any conducting system some distance from the balloon. While this is a distinct disadvantage to racing balloons, owing to increased weight, the tests are very interesting as they show the tendency of the wet fabric in diverting a discharge.

Figure 7 shows a discharge to ground some few feet distant from a balloon equipped with a cage or lightning rods. In Figure 8 the balloon has been wet. While there was some tendency for the balloon while dry to attract the arc, the point of discharge was too great, so that the arc struck to ground. In Figure 8, however, the field set up by the wet balloon was of sufficient magnitude to attract the discharge. The discharge followed the shunt path, then continued from the lower end of the cage to ground. Without the shunt path, the wet balloons were invariably set on fire by the direct stroke. In some cases the fabric seemed to be only slightly damaged. The escaping gas, however, was frequently ignited by the stroke, causing destruction of the balloon unless quickly extinguished.

The probability of a direct hit.—In the case of free balloons or blimps there would undoubtedly be a considerable difference between the wet and dry conditions in attracting a discharge in the vicinity. In other aircraft as now constructed, however, there would be little difference, wet or dry. In the tests on models placed near the path of discharge it was evident that the path of discharge was diverted an appreciable distance by the presence of the plane. It would seem that the probability of being struck would increase approximately as the square of the greatest linear dimension.

The nature of the electrical field, the polarity of the discharge, and the direction of the axis of the aircraft relative to the general path of discharge, are all factors which make it difficult to predict the effect of size in increasing the probability of direct hits. Figures 9, 10, 11, and 12 (fig. 10 only reproduced) show typical discharges to model planes showing the probable points of contact of the stroke.

Figure 13 shows a positive discharge of limited capacity striking a model Zeppelin. The discharge was not sufficient to cause the arc to continue to ground, but illustrates the effect of a large body free of ground. Immediately following the first discharge, another discharge was applied of sufficient magnitude to cause a discharge

not only to the model Zeppelin but from the rudder to the ground.

It is interesting to note that in all of the tests the fabric used on the Zeppelin and that on the fabric-covered duralumin airplane was not ignited by the discharges. This goes to show that the fire hazard is negligible where a path of high electrical conductivity is provided.

It would seem that the effective increase in size and the use of metal in the present construction of airplanes should do much to minimize the lightning hazard, even though little or no attention is given to protection.

A direct hit to the plane may possibly affect the pilot or passengers in one of the following ways:

(*a*) Direct hit.

(*b*) By forming a path for the discharge between conducting objects.

(*c*) Shock from induced charge.

(*d*) Sudden change in air pressure.

(*e*) Severe sound or pressure waves.

(*f*) Currents induced in the body by an electromagnetic field.

(*g*) Hazard due to the effect of intense light upon the pilot.

While the danger from some of these hazards may be absent in many planes, they can be largely reduced if not entirely eliminated in others by proper attention to details of construction, or by applying a protecting scheme which will establish the path of discharge at a distance from the pilot.

(*a*) *Direct hit.*—In general the possibility of a direct hit to the pilot is exceedingly small even in the low wing monoplane with open cockpit. The tests showed that the discharges would enter or leave through the propeller or nose, rudder, wing tips, or landing gear. A lightning rod projecting above and to one side of the pilot would insure the diverting of the stroke even though the pilot's head projected well above the fusilage. In large planes or Zeppelins the points of contact of the stroke would be considerably removed from the pilot or passengers, so that it would appear that the danger from direct stroke may be even less than that in the ordinary dwelling during an electrical storm.

(*b*) *By forming a path for the discharge between conducting objects.*—A discharge of lightning may carry a current far in excess of that available in any of the laboratories used for the production of artificial lightning. The fused wire in the basket shown in Figure 2 (not reproduced) can not be duplicated with the heaviest lightning discharges in the laboratory. Records taken at the forest rangers' stations show that a stroke of lightning may be sufficient to fuse a No. 14 copper wire. Tests on aerials have shown that wire of larger size is fused, all of which indicate currents exceeding several hundred thousand amperes.

The impedence afforded by conductors with this very high rate of discharge will cause a considerable drop in potential. This drop in potential causes the current to divide into multiple paths, the drop in voltage being sufficient to cause the bridging of appreciable air gaps where the impedance is not very large. It is therefore essential that the most careful attention be given to bonding. In order to reduce the impedance it is well to distribute the conductor in several parallel paths. This reduces the reactance and the voltage induced by the high rate of discharge.

It is evident that should the pilot come in contact at two points along a conducting member, he is likely to be subject to shock. The thorough bonding, the use of a low impedance multiple path as far away from the pilot as possible, together with a single point of contact with conducting material will eliminate the danger of shock from drop in potential due to the passage of exceedingly large currents.

(*c*) *Shock from induced charge.*—A pilot in an open cockpit may be subjected to an induced charge due to the collapse of the electrostatic field. It would seem that this charge would amount to but little providing the discharge did not cause the pilot to become frightened so as to lose control. The complete shielding afforded by metal cabin planes completely eliminates the effect of the induced charge due to the collapse of the electrostatic field. The same applies to Zeppelins.

(*d*) *Sudden change in air pressure.*—The intensity of lightning varies greatly for different strokes. It would seem, however, that the very severe discharge causes a rapid heating of the air and an increase in pressure in the immediate vicinity. The pressure set up where the air is free to expand is not as great as originally supposed. The fact that three balloonists have come through storms where the stroke was within a foot or two of them would indicate that the hazard from this source is not serious, even for the very heaviest discharges where the path can be moved out a few feet from the pilot.

(*e*) *Severe sound or pressure waves.*—The effect of the severe sound and pressure waves may be responsible for the shock suffered by pilots and others who have been within a few feet of lightning strokes. The duration of the effect seems to vary considerably with the individual, and may cause effects somewhat similar to those suffered from shell shock. Many of the factors producing shell shock are present although there are others in addition. The severity reduces rapidly with distance. It would therefore seem that using a construction which removed the point of contact between lightning and plane well away from the pilot will do much to eliminate any serious effects which may cause the pilot to lose even temporary control.

The pilot can, of course, be easily protected from sound or pressure waves by providing a suitable compartment or other sound-absorbing equipment.

(*f*) *Currents induced in the body by an electromagnetic field.*—A stroke of lightning may consist of a single discharge or several discharges within a very short space of time. The strength of the electromagnetic field will vary directly as the current in the discharge, and inversely as the distance. A current of 400,000 amperes in a stroke will produce a field of 2,620 maxwells at 1 foot distance; 262 maxwells at 10 feet distance, and 131 maxwells at a distance of 20 feet.

Any change in the electromagnetic field passing through either high or low resistance material will induce a voltage and current. The induced voltage and current will depend upon the rate of change in the magnetic field. It is evident that the lines of force passing through a person will induce currents, the action being similar to that in a high-frequency furnace. Several strokes in rapid succession may induce a greater current or potential than a single stroke of higher maximum magnitude but having a slower rate of change.

While it is possible to screen the electrostatic field, it is practically impossible to effectively screen the electromagnetic field so as to prevent the lines of force passing through objects in the vicinity of the field. The field may be set up by the current of a portion of the discharge in the air, or in a conductor in the aircraft. It would seem that the heaviest discharges taking place close to a person

may induce enough potential and current to effect the system, or at least paralyze the nervous system temporarily.

A study of the factors affecting the induced potential and current goes to show that the electromagnetic field may be materially reduced by removing the shunt path from the immediate vicinity, and by forming multiple paths around the pilot or passengers so that the field set up by the current in one path tends to neutralize the field set up in the other. The fact that some people have not been affected although within a few feet of the discharge would indicate that a reduction of the field strength by an appreciable amount would entirely change conditions and provide protection even for the most severe strokes.

Further investigation may show that the induced current does not constitute a hazard. The magnitude of the voltage generated and the current induced for heavy strokes in the immediate vicinity, however, would indicate that the possibility of affecting at least the nervous system can not be ignored without very definite proof to the contrary.

Although little has been accomplished in determining whether or not the shock or stunning effect is primarily due to electrical causes or to physical conditions similar to those producing shell shock, the same method will improve conditions for either case—which consists primarily in initiating the point of contact to the stroke as far away from the pilot as possible.

(*g*) *Hazard due to the effect of intense light upon the pilot.*—The light from a stroke particularly at night may have the effect of blinding the pilot when passing through the line of vision. At night the iris is wide open, and it is possible that the ultra-violet light might have some effect upon the pilot for a discharge striking the nose of the plane. In most planes, however, the discharge would be to one side and above or below the direct line of vision. It is believed that the hazard from this cause is small. While intense light may have the effect of blinding the pilot for a short time, any serious effect due to ultraviolet light may be eliminated by the use of glass in the windows or goggles which would absorb any injurious rays.

While the effect of lightning upon the pilot or passengers undoubtedly causes the greatest and most uncertain hazards, there are other hazards to the plane or aircraft which need careful consideration.

1. *Fire hazard due to ignition of combustible material used in the construction of the plane.*—The fire hazard to the metal plane is negligible although intense heat exists at the point of contact with the lightning and the plane. The fire hazard is practically negligible even where material which will support combustion is used. Where an inflammable covering is used in contact with metal, the fire hazard is apparently negligible. Inflammable material which is readily ignited may be set on fire by the crater. The severe rush of air following the stroke has the effect of extinguishing the flame, the discharge being in the nature of an explosion. The rapid expansion of the gases even in the fabric apparently absorbs sufficient heat, which together with the blast of air following the discharge prevents ignition. This is particularly true where a fabric is used to cover duralumin or other metal. The heat conduction of the metal and the low resistance of the path afforded tend to not only absorb the heat but reduce the energy dissipated.

Figure 14 (not reproduced) shows the effect of artificial lightning upon the rudder. It will be noted that the fabric has apparently been exploded at the points of contact, the fibers being torn apart, the effect being very similar to that of popping corn.

A rather severe series of tests run on a model Zeppelin covered with fabric showed that it was impossible to ignite this fabric with the artificial lightning. The history of Zeppelins has also indicated that this danger is small unless conditions approximate those of the gas-filled free balloons.

2. *Fire hazard due to ignition of explosive gases.*—A discharge may take place between conducting surfaces not properly bonded, or from isolated tanks or conductors separated from the bonded structure by small air gaps. The discharge may be produced by the release of a bound charge following the collapse of the electrostatic field, or due to the impedance drop in conductors making up the structure, or by the change in the electromagnetic field. These induced discharges are similar to those noticeable in the ordinary dwelling where a discharge takes place between wiring and conduit or fixtures following a stroke of lightning near by. Should these discharges take place in a pocket of gas, an explosion may result. It is therefore important to either thoroughly ventilate all pockets which may accumulate gas or to adopt a construction so that a discharge can not take place. Vents or openings for scavaging explosive gases should be protected with a screen similar to that used in a safety lamp.

3. *Weakening or destruction of metal parts due to current in the discharge.*—In aircraft having a metal structure there is ample conducting capacity so that a serious temperature will not be reached in any of the metal parts. However, should the construction be such that the current is confined to small members or to important connections having a high resistance, it is possible that the heating may seriously affect the structure and lower the mechanical strength. This is important, as some of the alloys are materially affected by a temperature far below the fusing point.

While the varnishing of the surfaces and joints together with the oxidation of the surface go to produce a joint of high resistance, it must be remembered that the riveting cuts through the edge and forms a path of low resistance. A number of point contacts formed in this way results in a joint of very low resistance so that little or no damage need be feared even though cross section of metal in good contact is small. Where metal parts simply come in contact or are held a short distance apart, considerable energy may be dissipated in the joint.

It would seem that the greatest hazard due to heavy current affecting the strength of metal parts is that due to control cables or stay wires in nonmetal planes. Discharges direct to the rudder showed a very appreciable rise of voltage on the control cable, although in the plane tested a small percentage of the current only was carried by the control cable—the major part going through the hinge and metal framework.

4. *Breakdown of insulation in the ignition system.*—Most of the ignition systems are fairly well insulated and have to withstand the relatively high voltages generated in the normal operation of the engine. Care should be taken so that conductors of the ignition system do not form a shunt path. In addition, the conductors should be exposed as little as possible. The ignition systems apparently are more immune from trouble than would generally be expected. This seems to be due to the fact that the rise in voltage is limited by the discharging of the spark plug either inside or outside the cylinder.

Figure 15 (not reproduced) shows the ignition system being subjected to a discharge of over 1,500,000 volts. The discharge is striking the spark plug and lead on one of the cylinders. A number of similar discharges apparently had no effect upon the magneto or other parts of the ignition system. A small shield placed over the plug easily diverted the discharge.

5. *Back fire.*—It is evident that a discharge striking a plug or lead may cause a back fire or the engine cylinder to fire out of turn. A series of tests were made with the engine running so that the discharge would strike the propeller or ignition system. The propeller used was wood with a metal shielding which ended some distance from the hub.

Figure 16 shows a discharge striking the end of the propeller. The discharge is then shown jumping from the metal shielding on the propeller to one of the spark-plug terminals, as these happen to end about in line with the end of the shielding. A number of discharges apparently had no effect although it appeared that the impulse from one cylinder was lost. The effect, however, was so slight as to leave this point in doubt. A small shield placed in front of the rod effectively drew all of the discharges. While the hazard is exceedingly small, it would therefore seem to be good insurance to prevent a discharge of this kind to the ignition system which might break down the insulation of leads or the magneto.

6. *Damage to instruments.*—During one of the endurance flights at Cleveland the plane was struck by lightning and the instruments so damaged that landing was made. An examination of the instruments did not show any electrical damage due to the conduction of current. There was an indication that the diaphragm in the instrument which was connected to the Pitot tube used for determining velocity might have been damaged by the pressure set up. In the tests which were run some time later it was evident that the Pitot tube might be a point of contact for the stroke, in which case sufficient pressure might be set up so as to destroy the rather delicate diaphragm. A sudden air pressure set up by the stroke in any other way might of course have produced the same effect.

Should it appear that there is danger to instruments from the pressure set up, it would be a comparatively easy matter to prevent this by placing a baffle in the line between the Pitot tube and the instrument, preferably with a surge chamber between the restriction and the instrument. Other instruments could be inclosed in a chamber with a window.

The electrical fields set up by a heavy discharge in the immediate vicinity may damage magnetic instruments or those in which an induced current may cause a breakdown of insulation. While electrostatic screening is comparatively easy, screening for the electromagnetic field is very difficult and it would follow that instruments which are likely to be damaged by a strong magnetic field should be so placed that the path of discharge in the frame or surrounding objects is removed as far as possible.

7. *Damage to rotating parts from passage of current.*—The damage to rotating parts may be serious where a heavy current must pass through an important bearing. Discharges with currents as high as 100,000 amperes showed no appreciable damage on the main bearing, or upon ball bearings. Since this discharge lasted for a fraction of a microsecond only, the tests do not prove that damage from this source can be entirely ignored. In general, however, it would seem that a discharge striking a metal propeller would flash from the shaft to the face of the engine case without causing any damage. However, should the discharge take place in the bearing, it is possible that trouble would result. Owing to the resistance of the bearing, it is comparatively easy to provide a shunt path between the propeller shaft and housing so that the oil film will not be punctured by a discharge.

While the energy stored in the test condenser is of the order of 10,000 watt-seconds compared to 10,000,000 watt-seconds in the discharge of lightning, it must be remembered that the energy is dissipated almost entirely in heating the air so that the energy dissipated in a bearing may not be any more with a lightning stroke than that under laboratory conditions, unless the discharge consists of a number in rapid succession liberating a considerable amount of energy.

8. *Sudden change in pressure on adjacent surfaces.*—The sudden change in air pressure following a heavy stroke will probably not exceed that frequently occurring under normal flight. Should a discharge be close to and parallel a surface, it is possible that a heavy effective pressure may be set up tending to cause the collapse of same. It is this sudden change in pressure which probably accounts for the tearing of fabric.

It is evident that the larger the spread of the conducting surfaces the greater will be the danger of a stroke including the airplane in its path to ground, or from cloud to cloud. While the use of an aerial extending some distance below the plane will tend to increase the danger of a stroke it must be remembered that this will at least keep one of the points of contact of the discharge at some distance from the plane. This advantage may more than offset the increased probability of a strike. The use of a loop set does not change the hazard in any way over that where no radio set is used. The use of a strut or mast extending above the plane for an aerial would seem to be an added protection as it would tend to keep the point of contact at a distance.

The insertion of a resistane or impedance between the antennæ and instrument with a shunt path to the frame of the aircraft will provide ample protection, the protection probably being much more effective than that provided for the ordinary house radio set using an outside aerial.

While hot gas is a good conductor, the question of the engine exhaust forming a conducting path which would tend to induce a stroke to the plane does not seem to be an appreciable hazard. In all of the tests the effect of the exhaust gases could not be noticed. In the many tests made there was no indication that a low resistance or conducting path was created by the hot gases. In fact, it would appear that the dielectric strength of the air was apparently increased by the wind or pressure produced by the propeller. While the gases are conducting for a very short distance from the exhaust, this hot gas is soon cooled by the mixing of the strong air current produced by the propeller, so that no effect upon a discharge can be expected.

In conclusion it may be said that while information is lacking as to the effect upon the person, much can be accomplished to remove the danger of this effect by giving attention to the various factors involved. While the hazard is exceedingly small, it is possible that still further improvements may be effected by taking advantage as opportunities in design and construction present themselves.

Further information upon the effect of shock will doubtless show that the hazard is not very great, although

it may appear to be necessary to protect the pilot from sound or other conditions during a storm. Where the pilot has a fear of lightning, it is possible that tests or checks might be devised which would remove this fear.

Anything which will permit the safe landing of the plane or provide automatic control while the pilot is stunned would do much to elimiate the hazard that now exists. Owing to the increased reliability of aircraft, less attention will be paid to storms. While this will tend to increase the lightning hazard, it would seem that the present hazards can be more than offset by careful attention to the various factors tending to produce reliability.

OBSERVATIONS FROM AIRPLANES OF CLOUD AND FOG CONDITIONS ALONG THE SOUTHERN CALIFORNIA COAST

By JOSEPH B. ANDERSON, Lieutentant, United States Navy

[United States Naval Air Station, Anacostia, D. C., July, 1931]

While serving as aerological officer of the aircraft squadron, Battle Fleet, at the fleet air base, San Diego, Calif., during the summers and autumns of 1928 and 1929, many previously formed ideas of the California weather underwent a considerable change. Perhaps the most interesting of these was that, in so far as aerological officers and aviators are concerned, the weather lacks much of the regularity which had been expected from the claims of the Californians and descriptions of tourists. It is true that over the land adjacent to the ocean there is little rain during the summer, few thunderstorms and gales, and that the sky generally becomes cloudy during the night with clouds that burn off early the next morning, leaving the day more or less cloudless. (At sea the clouds may, or may not burn off, a fact of little concern to those on land but often vitally important to the aviator and navigator.) With this the regularity ceases, for the velo [1] clouds frequently form over land as early as 2 or 3 p. m., and continue until early morning, mid forenoon, or even until noon, at heights which vary from 1,000 to 4,000 feet, according to conditions. If the clouds form at an altitude of 2,000 feet or more, they are of little moment to the pilots of aircraft. However, when they develop at such an altitude that their bases are less than 1,000 feet, there is a considerable likelihood that they will continue to lower until they reach the surface, when, to all practical purposes, a dense fog results.

Since the flight operations are often delayed, cut short, and even rendered impossible by a velo cloud that fails to burn off at the usual time, or that forms earlier than the regular time, the aerological officer receives many inquiries from squadron commanders asking the time the sky will clear, the time that the clouds will form at night, what the ceiling will be, whether night flying is advisable, if the clouds will clear at sea during the day, and many similar questions. Obviously the answers to these questions are not always apparent.

During the summers of 1928 and 1929 many schemes were adopted in an effort to find the why and the wherefore of the southern California coast weather in the belief that if they were found, the when could be more easily determined. The current weather maps were available but did not explain many of the observed details. Old maps were studied in an attempt to classify them in accordance with certain very definite types of weather which were observed, but with little success. A study of the actual changes in the weather during these types proved to be more fruitful of results and accounted for many of the successful forecasts; but at times a very definite type would change suddenly, apparently without cause, and a more or less complete failure in the forecast would result. The lack of reports from the south and west made the identification of fronts difficult, and even impossible, much of the time. Further, meteorological literature was searched for a satisfactory explanation of presence of the velo cloud during the night and its absence during the day, at least over land. The explanations found did not appear to be of great practical value in forecasting the cloud conditions.

There remained, however, the aerograph records which had been made during the many aerological flights at the naval air station, and the opinion was soon formed that if an understanding of the velo cloud, and its many changes, were to be gained it would be from the visual observations and instrumental records obtained during flight. As stated, there were many records available, but these did not seem to give the detailed information desired. Practically all records made during the summer and autumn months showed that a temperature inversion existed over the air station during these seasons, and other records showed that the inversion was frequently present during the other seasons. This, of course, was already well known, as were the several theories which had been advanced to explain the cause of this condition, such as the Imperial Valley air theory and the settling air, or subsidence, theory. (The former states that the warm, dry air above the base of the temperature inversion [2] is air which has moved westward over the mountains from the Imperial Valley to the coast, while the latter explains the temperature and dryness of the upper air as due to the presence of the HIGH in the upper atmosphere over the semi-permanent thermal LOW at the surface in Lower California. The slow descent of air from this HIGH is given as the cause for the heat and dryness aloft.) The main points noted in the old records were that the temperature of the air decreased *rapidly* with the altitude until the base of the inversion was reached, then the temperature increased with continued increase in elevation to some definite point above which a more or less normal decrease in temperature occurred. The record showed that as a general condition the relative humidity increased from the surface to the base above which it decreased rapidly, usually to 50 per cent, or less; often to between 50 and 25 per cent; again, to less than 25 per cent; and occasionally to almost 0 per cent. However, it was found from observations during some of the aerological flights that there were inaccuracies in the temperature and relative humidity traces on the older records and also on the ones being made during the early summer of 1928. The inaccuracies in the relative humidity traces were caused by the type of humidity element installed on the aerograph, a type much too sluggish to record details during a routine climb. The temperature inaccuracies referred to were caused by the frequent delays in take off when the sun was shining. Experience showed that unless especial precaution were taken under these conditions a temperature of 2° to 5° C. above the true air temperature would be recorded at the time of the

[1] Velo cloud, the name given by Californians to the high fog or stratus cloud that drifts over land and generally burns off as the day advances.—*Editor*.

[2] For the sake of brevity the word "base" alone will be used on subsequent pages, the meaning in all cases being the same as in the present instance.

FIGURE 1.—Discharge from large condenser to ground at the high voltage laboratory of the Ohio Insulator Co. Photograph taken by synchronized camera

FIGURE 4.—Basket equipped with Van Orman cage for protection against lightning

FIGURE 2.—Showing the basket used on the *City of Cleveland* balloon which was struck while the balloon was at least 5,000 feet in the air

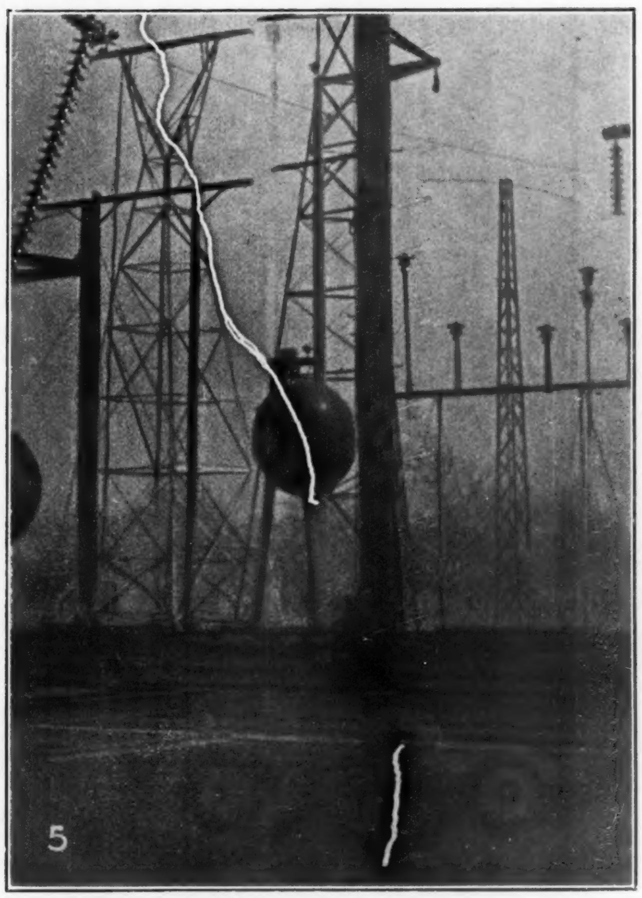

FIGURE 5.—Dry-hydrogen balloon with antennæ attached, subjected to lightning discharge without damage to balloon

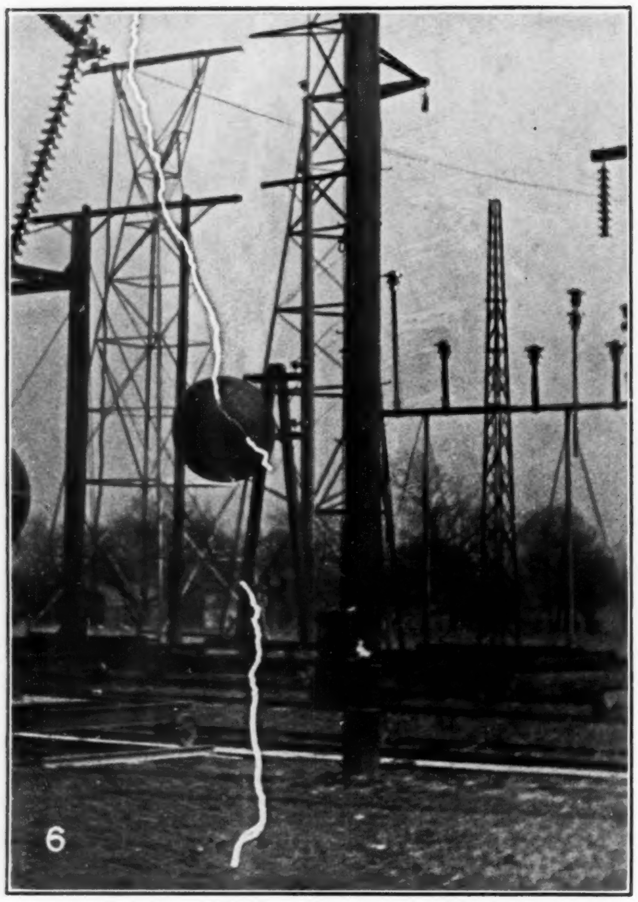

FIGURE 6.—Photograph shows discharge to the wet balloon causing its destruction

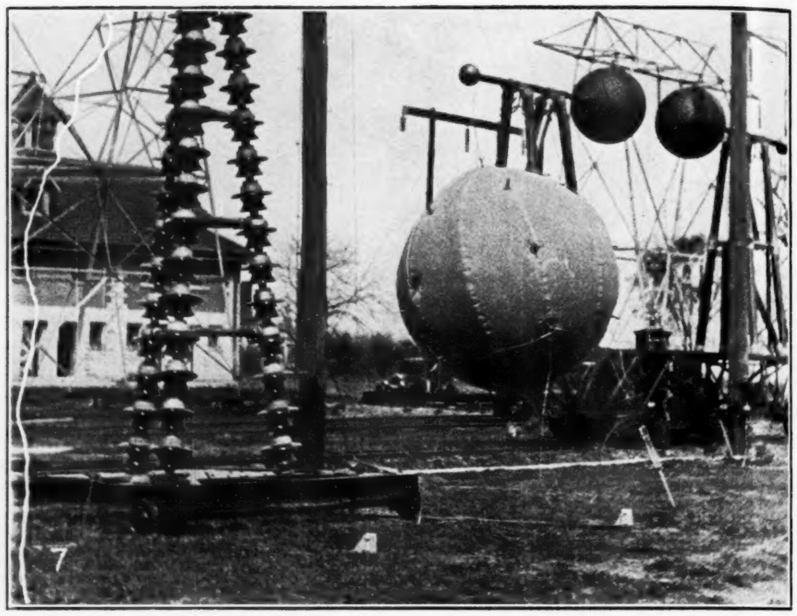

FIGURE 8.—The field set up by the wet balloon attracted the discharge which terminated on lightning rod raised from surface

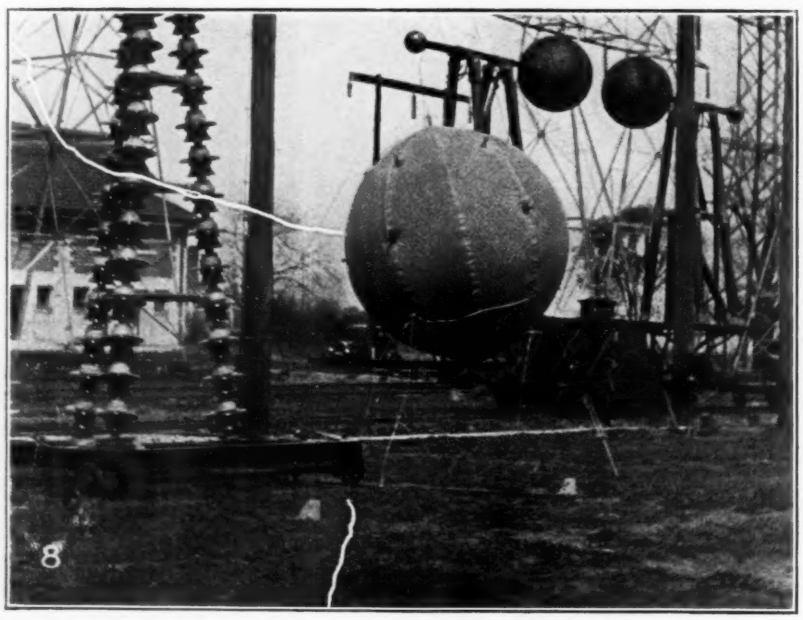

FIGURE 7.—Discharge taking place to one side of dry balloon equipped with cage and lightning rods

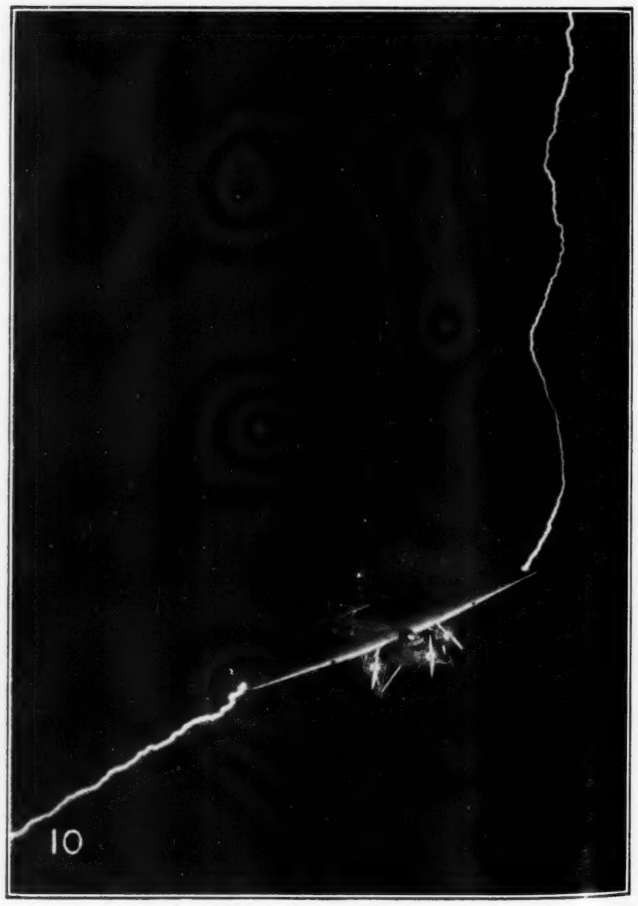

FIGURE 10.—Discharge entering and leaving from wing tip

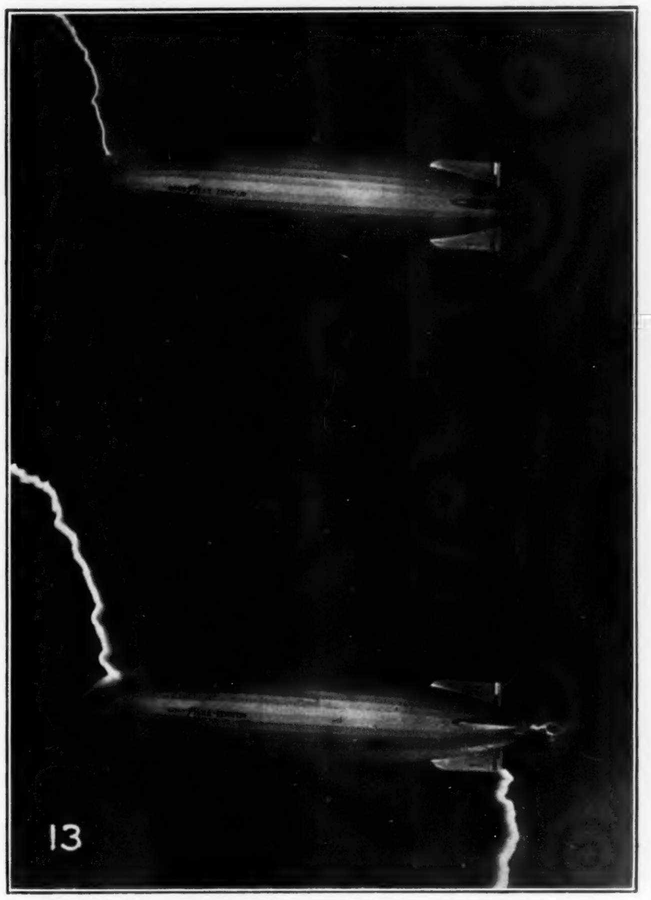

FIGURE 13.—Upper view: Discharge of limited capacity striking model Zeppelin. Lower view: Heavy discharge striking Zeppelin and continuing to ground

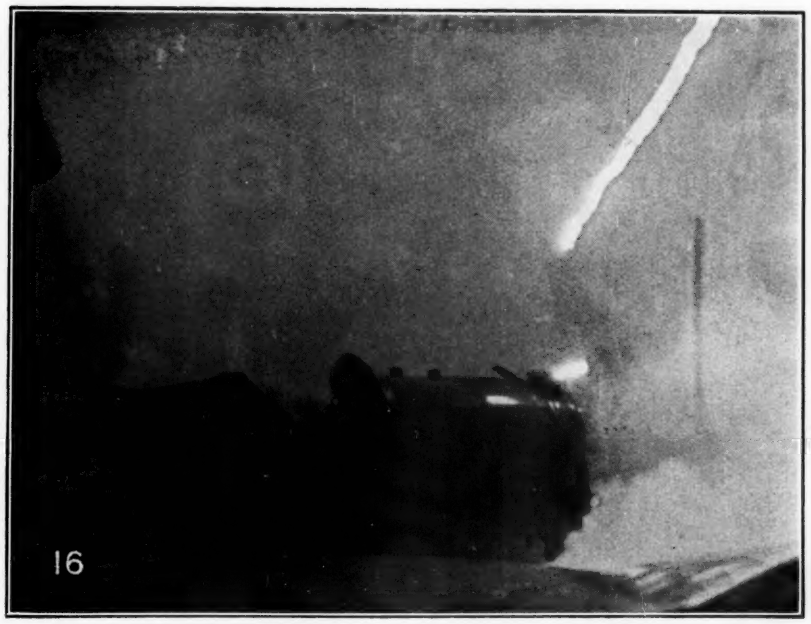

FIGURE 16.—Discharge to propeller while in operation. Discharge strikes from termination of metal on propeller to ignition system opposite

beginning of the flight and would, therefore, show a much too rapid fall in temperature from the surface to the base. The relative humidity records were greatly improved by the installation of new hairs in the aerograph, and the temperatures at take off were corrected for the naval air station by the introduction of certain modifications in the routine flights by Lieut. A. L. Danis, United States Navy, shortly after he reported for duty as aerological officer. Correct surface temperatures were more easily obtained by the aircraft squadrons' personnel since the flights were made from the water in a seaplane.

During 1928 routine aerological flights were being made daily, except Sundays and holidays, by the naval air station personnel, but because of the pressure of other duties only a limited number were made by the aircraft squadron's aerologist. During these flights, however, the opinion was soon formed that although the routine flights were of great value from the standpoint of information in general, they were not entirely suited to a study of this kind. This was due to the following causes: (1) being routine, they were scheduled for about the same hour each day; (2) the rate of climb, which was about 300 feet per minute, was too rapid for the recording of many details; (3) the length of the flight was usually quite limited owing to the fact that the data had to be worked up as soon as possible for use in the morning forecast and forwarding to the Weather Bureau, and also because of other operations scheduled for the plane.

During the summer and fall of 1929 it became possible to make many aerograph flights, not of a routine nature, to investigate special features of the local weather. Data gained from these flights, together with information received through conversation with officers who had cruised in various parts of the eastern Pacific Ocean, ship reports, and information obtained in the Weather Bureau office at San Francisco, led to a survey of the prevailing conditions along the coast and the adjacent ocean, and a study of their relation to the inversion and cloud conditions. This survey has shown that the inversion is normally a sea condition and exists over the land only in areas where surface air from the ocean has penetrated; that it is influenced at times by air from the Imperial Valley, or other inland districts, which is evident from the fact that pilot balloon records and observations of upper clouds and forest fire smoke show definite easterly winds aloft on many days; that much of the time inland air is not present, and therefore not necessary, because at times both surface and upper winds are from the sea for periods of several days. It is further quite evident that although the inversion does greatly influence the fog and velo cloud conditions, it is not the cause of either.

It was known that the inversion extended continuously along the coast from San Diego to San Francisco, and for a considerable distance to sea. It was also known to cover the land areas west of the Coastal Range and to exist over San Francisco Bay. During this survey it was learned that it extends north along the coast to the southern part of the State of Washington during the summer and, according to the best information available, extends 200 to 300 miles to sea. Numerous aerograph flights were made to points 30 to 40 miles west of San Diego, and also to the south, and the inversion was found to exist on all such occasions. On these flights, from altitudes of 8,000 to 12,000 feet, the characteristic clouds and haze could be seen to distances of more than 100 miles at sea, indicating that the inversion extended at least 100 miles or more to the west, southwest, and south. In February, 1929, the U. S. S. *Saratoga*, while en route from San Diego to Panama, experienced inversion weather well south along the California Peninsula. An aerograph flight 800 miles south of San Diego revealed a well formed inversion, and velo clouds covered the sky for another 200 miles. In June of the same year, while returning from Panama, the *Saratoga* passed under the characteristic velo cloud at about the same point off Lower California and continued under the same inversion conditions during the remainder of the trip to San Diego.

From all information obtained it seems safe to assume that during the summer the inversion ordinarily extends from southern Washington to a point 800 to 1,000 miles south of San Diego, west from the coast for a distance of 200 to 300 miles, and over the land areas between the ocean and the Coastal Range. This gives an area about 2,000 miles parallel to the coast, and about 250 to 350 miles west of the Coastal Range. Finding it difficult to explain an inversion over such an area, and with such different wind conditions, by the explanations given in the fourth paragraph (i. e., heated air from the inland and a settling of air from a HIGH in upper atmosphere) a more satisfactory explanation was sought. Upon consulting pilot charts it was found that the prevailing winds along the coast are from the northwest, covering a belt from Washington to Lower California, and about 200 to 300 miles to sea. Just to the west of the northwesterly wind belt there is a similar area with the prevailing winds from the north, and to the west of this, or beginning about 500 to 700 miles off the coast, the northeast trade winds are found and they continue to and beyond Hawaii. The characteristic weather of the northwesterly wind area is of the inversion type, and that of the trade winds in summer is of the instability shower type. What the characteristic weather is within the northerly wind belt was not determined. It was further found that the temperature of the water along the coast from Washington to Lower California is colder than that at a distance offshore, and that the water temperatures west of the San Diego-San Pedro area continue to rise to and beyond Hawaii. As would be expected, the temperatures fall to the north from San Diego and rise to the south, but the temperature changes along the coast, north and south, are not as great as the rise in an equal distance to sea, especially to the west and southwest. According to the Hydrographic Office Publication No. 84, Mexican and Central American Pilot, the warmest water of the eastern Pacific is found in the region 1,000 to 1,500 miles south and southwest of San Diego where the mean temperature in August is said to rise to 85 F.°, at times. The temperature of the sea water in the San Diego area at the same season is about 60° to 62°F. When it is remembered that during this same season the inversion is best developed, this fact becomes important.

The pressure gradients over southern California and the adjacent ocean are ordinarily very weak, especially in the summer, and the average surface winds correspondingly light. However, during the heated part of the day the sea breeze frequently attains a velocity of 12 to 18 knots, at least during the early part of the afternoon. It has been reported from observations taken on board some of our battleships while cruising west of San Clemente Island, which is about 60 miles offshore, that the winds in that district are frequently stronger than those nearer land. The reports referred to stated that the winds experienced were 18 to 25 knots, whereas a check showed that the winds along the shore on the days indicated were 10 to 15 knots. Ordinarily the

winds aloft are likewise moderate, but occasionally very high velocities occur.

As stated above, the prevailing direction of the surface wind along the eastern edge of the Pacific is northwesterly. Probably it would be more accurate to state that along the immediate coast the prevailing winds are from the northwest to west. Easterly surface winds seldom occur during the summer except under Santa Ana wind conditions.[3] Prevailing directions at 500 to 1,500 meters are also northwest, but above that height the prevailing direction is southwest. These statements have been made after examining a table published in an article, "Temperature Inversions at San Diego, as Deduced from Aerological Observations by Airplane," by Mr. Dean Blake, of the Weather Bureau office at San Diego in the MONTHLY WEATHER REVIEW, June, 1928. The conclusions drawn from this table by Mr. Blake are as follows:

> Even the most cursory examination forces us to draw several obvious conclusions, namely: (*a*) That at virtually every level, winds were from the ocean the larger percentage of the time; (*b*) that between 2,000 and 10,000 meters the percentages from the land and ocean remain fairly constant; (*c*) that beyond 10,000 meters the few soundings obtainable showed an increasing frequency from the ocean; (*d*) that the prevailing direction at all levels was southwest; (*e*) that the northwest currents believed to predominate at the higher levels, summer as well as winter, were not in evidence.

It is not understood how Mr. Blake derived the conclusion marked "(*d*)" for the table, based on pilot-balloon soundings for June, July, and August during the years 1924 to 1927, inclusive, as the naval air station, San Diego, clearly shows the preponderance of northwest and west winds at the surface, and northwest winds at 500 to 1,500 meters. Aside from this, the conclusions appear to be sound. Regarding the velocities of the winds, Mr. Blake states:

> Although a chart has not been prepared for the velocities during the same period, it was further observed that at the soundings under 2,500 meters they were rarely other than light, and when from the eastern, or land, quarter were more in the nature of a drift than a current.

These conclusions are believed to have been substantiated during the summers of 1928 and 1929, except at the times of Santa Ana winds when very high velocities were sometimes found.

Continuing in this article, Mr. Blake states:

> If we can make our deductions from four years' record, then there must be other causes for the steep inverted gradients besides an overflow of hot air to the coast from convectional action in the Imperial and Colorado Valleys, as inversions occurred at every observation regardless of wind direction.

It is believed that sufficient facts have now been presented to show this "other cause." It will be remembered that practically all of the air over the coastal region comes from the sea. Except immediately along the coast to the north, the water everywhere, within a distance of 1,000 miles, is warmer than at any given point along California. This means that air from any portion of the Pacific Ocean, while approaching the coast, must pass over colder and colder water, and especially is this true when the air moves from the south or southwest where the temperatures rise quite rapidly with distance offshore. The processes which takes place as warm air passes over the colder water are relatively simple. The first effect is the cooling of the surface air to the temperature of the water. Due to friction between the air and the water, especially where waves have formed, the lower layers of air become turbulent and are filled with eddy currents which mix the cooled air with the warmer air above it, each mass leaving the surface tending to cool adiabatically as it rises. At first the surface air is thrown upward into warmer and less dense air and considerable energy is required. This energy is furnished by the wind. After the process has continued for some time the temperature of the air in this stratum decreases rapidly with altitude, in time equaling the dry adiabatic lapse rate. Above this stratum the temperature increases for a greater or lesser distance, and then decreases at approximately the original rate. After the dry adiabatic lapse rate has been established near the surface it will not require as much energy to throw a mass of air from the surface to a given distance aloft as at the beginning, hence, assuming the same wind velocity, surface air will be thrown to a greater height. There is a limiting distance, however, for each wind velocity which will vary somewhat with conditions of temperature and humidity.

Although statements were made above showing the prevailing wind directions for the various areas along the coast, it is not to be assumed that such winds are constant. For instance, the table of Mr. Blake, which was prepared from the afternoon pilot balloon records and therefore show the conditions at that time of day, shows that the surface winds were from the northwest on about 40 per cent of the occasions, from the west about 30 per cent, and from the southwest about 25 per cent. This shows that it is perfectly possible for air to approach San Diego from any portion of the eastern Pacific. Should a mass of air with a normal lapse rate of 3° F. per 1,000 feet move from the very warm area to the south and southwest, where its surface temperature was 80° F., it would reach San Diego with a surface temperature of about 60° F. If clouds have not developed, its lapse rate from the surface to the base, assumed to be 1,500 feet, would be approximately equal to the dry adiabatic, and the temperature at the base would be about 8° F. lower than at the surface, or about 52° F. The temperature of the air above this point would increase from the minimum of 52° F. to some point, say 1,000 feet higher, where a maximum temperature would be found which, in this case, would be approximately 72° F. This mass of air would, therefore, reach the coast with a 20° inversion, and the maximum temperature at 2,500 feet would be 12° F. higher than that of the surface air just off the coast. This maximum temperature would also be at least as high as that of the surface air at the fleet air base, or San Diego, on the normal day. By following a mass of air from any other point of the eastern Pacific, except almost directly along the coast to the north, it will be seen that it will reach San Diego, or any other point on the California coast, with an inversion but, of course, less in amount as the source of the air is farther to the north. Many degrees of inversion have been recorded by the aerographs, ranging from no inversion to one of 29° F., also with maximum temperatures aloft less than the surface temperature, equal to it, and greater. While this thermal stratification of the lower atmosphere is being established, important humidity changes occur. Once the inversion is formed, the water vapor, both the original and that received from evaporation, is distributed in the stratum below the base by the turbulence, and in this way the moisture content of the lower stratum is increased, while above the base the amount of water vapor remains about the same as it was originally. The surface turbulence causes the relative humidity to increase rapidly from the surface to the base. This, with con-

[3] Santa Ana wind or simply Santa Ana—A name given by Californians to a strong dessicating wind having a northerly component which under favorable pressure conditions blows through passes in the Santa Ana Mountains of southern California.

tinued evaporation, ultimately causes the dew point to be reached, following which clouds begin to form. Clouds and fog do not necessarily form early in this journey to the coast, both because the original air often does not have an especially high relative humidity, and also because the air does not come into contact with much colder water suddenly, as it does over the Grand Banks, in the Atlantic.

From what has been said above it appears that any mass of air approaching any point on the Pacific coast south of the State of Washington from a considerable distance at sea, except almost directly along the coast to the north, must develop an inversion very similar in characteristics to those observed day after day in the San Diego area.

Although both the surface and upper winds carry air from the sea to the land by far the greater percentage of time, still on some occasions there is a definite air flow from the land. A well formed Santa Ana wind represents the maximum development of such conditions. Santa Ana winds are caused by high pressure areas over the Central Plateau region with relatively low pressure off lower California. Such a pressure distribution causes air to flow from well inland to the coast as northeast winds. In approaching the coast the air descends from the plateaus and mountains to the sea level and is heated both adiabatically and by the highly heated valleys over which it passes. At times the winds at the surface reach, or exceed, gale force, while very high velocities frequently occur aloft. This air reaches the coast very hot and dry, and with considerably less density than that adjacent to the surface of the ocean, so it is forced to rise from the surface soon after passing the coast line. An exceptionally good illustration of this occurred during the summer of 1929 when a Santa Ana of more than usual intensity caused northeast surface winds with gusts exceeding 35 miles per hour at North Island, and caused such heavy clouds of dust that flying was discontinued during the afternoon. During this time the U. S. S. *Aroostook* was conducting exercises at sea, about 10 to 15 miles southwest of the naval air station. At no time did the *Aroostook* encounter northeasterly winds, but was in light westerly winds during the whole afternoon. The Santa Ana winds continued the next day but with considerably less velocity, no gusts exceeding 30 miles per hour having been recorded. At the time of these maximum gusts a large bombing and torpedo plane (*T4M*) took off to calibrate altimeters at 6,000 feet. The pilot gained the desired altitude at a point about 4 to 6 miles southwest of North Island and, upon signal, leveled off, but instead of remaining at 6,000 feet the plane continued to ascend to 6,900 feet regardless of the fact that the pilot was attempting to stop the rise. Before reaching the maximum altitude the pilot turned to the observer and indicated his inability to maintain the desired level. Although the cause for the strong ascending currents was not fully recognized at the time, another attempt was made farther at sea and the proper altitude was maintained for five minutes without difficulty. No reports were received from the surface craft on that day, but it seems safe to assume that the northeast winds did not remain at the surface for a greater distance than 4 or 5 miles after crossing the shore line. Through conversation with aviators and officers of the Battle Fleet, other instances have been learned of where vessels have experienced normal conditions within 15 to 20 miles of the shore at times when strong Santa Ana winds were reported at near-by ports. However, that the strong northeast winds frequently proceed hundreds of miles to sea in the upper levels is proved by reports of dust clouds and sand storms by ships several hundred miles at sea.

During the summer of 1929 aerograph flights were made both during and immediately following several Santa Ana winds. As would be expected it was found that the temperatures, both at the surface and aloft, were much above normal, and that the relative humidity, very low at the surface, approached 0 per cent aloft. As soon as the intensity of the Santa Ana decreased sufficiently to allow the sea breeze to be reestablished over the coast it was found that the characteristics of the stratum below the base had changed little, if any, from the normal, but aloft the high temperatures and very low humidities continued for several days.

The above paragraphs show the principal characteristics of inland and ocean air approaching the coast, that from land being hotter and much drier than that from sea. Just as Santa Ana winds are of rare occasion, so are winds of the solid current type from sea, for, as stated above, the pressure gradients are generally very weak over that portion of the sea during the summer. A special chart was prepared to study the inversion conditions on which all pilot-balloon soundings made at the naval air station during the latter part of the summer of 1929 were entered by means of arrows, flying with the wind, at the various altitudes. Red arrows represented easterly or land winds, and blue represented winds from the ocean. A study of this chart gave the impression that at times the air along the coast line frequently drifts inland for a day or two and then drifts to sea, or vice versa. This chart was not started until late in the investigation, and owing to other duties there was no opportunity to study it as fully as desired. The most interesting features noticed were that with a slow drift from land the upper air temperatures rose and relative humidity fell, while in apparently the same air drifting back from sea a day or two later the temperatures had fallen and the relative humidity had risen somewhat.

The main points brought out in the foregoing paragraphs are as follows:

(*a*) By far the greater portion of air reaching the California coast both at the surface and aloft, comes from the ocean.

(*b*) Air reaching the California coast from practically any part of the Pacific Ocean will have developed an inversion by the time the coast is reached. This air will have a considerable amount of moisture in the warm air above the base.

(*c*) When air flows over the coast and adjacent ocean from well inland it causes a larger inversion than is caused by air from the sea, and the amount of moisture above the base is very small.

(*d*) The upper air over the coastal waters and adjacent land is ordinarily a mixture of air from various areas, sometimes a mixture of inland and ocean air, but more often a mixture of air from various regions over the ocean. The inversions which occur under these conditions have characteristics intermediate between those of (*b*) and (*c*).

Velo clouds form in the moist stratum of air below the base as a result of processes to be described in a later paragraph. If the temperature of the surface air is considerably above that of the water toward which it is moving, or if it is highly humid before the cold water is reached, low clouds, or fog, will form far at sea and move landward with the air mass. This is especially true in the case of air from the south and southwest. On the other hand, if the temperature of the air approaching the

colder water is only slightly higher than that of the water along the coast, or if its vapor content is relatively small, it may reach the coast with a well-developed inversion without either clouds or fog. However, if this air continues in contact with the ocean for any considerable length of time clouds will ultimately develop, because evaporation constantly adds water vapor to the lower stratum, and turbulence distributes it. It was stated that the turbulence in the lower atmosphere causes the cooling of air below the base and that this cooling might, in time, cause clouds. Solar radiation, however, opposes this and is the controlling influence most of the time during the day. A much more effective cause for cloud formation is found at night when radiation from the top portion of the moist stratum causes the already cold air just below the base to become colder. This, ultimately, results in instability, and any further cooling will cause convection. Obviously, these processes are operative throughout the night and the dew point will ultimately be reached. This accounts for the fact that the velo cloud forms only during the latter part of the afternoon or at night, and burns off during the next day.

Velo clouds always develop in the lower stratum where evaporation, turbulence, and convection are operative. So far as has been learned there always is an inversion above the cloud sheet; there certainly was on all occasions when observations were made in 1928 and 1929. Although these clouds are not formed by an inversion, but by the conditions in the stratum below the inversion, it does have a marked influence on them after they are formed. The height of the base is, in many cases, the determining factor as to whether the condensation will result in clouds or fog. The rate of increase in temperature above the base, and the amount of water vapor present, determine whether or not the altitude of the base will remain the same, or whether it will rise after condensation begins. This has a very definite influence on the height of the cloud sheet, its thickness, and whether or not it will develop downward to the surface. It is this lifting of the base through convection and condensation that causes a new mass of air from the south or southwest to so often produce fog at first and later only velo cloud.

It is believed that the "more satisfactory" explanation of the inversion, sought in an earlier paragraph, has been found, namely, that the inversion is a sea condition and is caused by the cold water along the coast. It explains why the inversion extends so far to the north and south and such a short distance east and west. It explains also why the inversion exists with deep westerly winds as well as winds from shore, and under pressure conditions which almost positively preclude the subsidence theory. Accepting the theory that the velo cloud is caused by thermal convections opens the way to understand some of the peculiar habits of the inversion and the base. It also explains some of the most interesting types of the irregular weather and, it is believed, it puts a very useful instrument into the hands of the forecaster who is compelled to answer the whens, the whys, and the how much.

The following paragraphs deal more directly with the observations made at San Diego during 1929, telling how the flights were made, what special conditions were observed, and how certain observations tend to substantiate the foregoing explanations regarding the inversion and the velo cloud.

Practically all of the flights were made in a seaplane, or an amphibian plane, over the ocean, and the air explored with a standard Friez aerograph attached to the outer portion of the right wing. During the period of these flights, aerological flights with the same type of aerograph were being made at the naval air station, San Diego, in a landplane which generally flew inland. At times it was arranged so that special flights were made to sea and inland simultaneously, and the records compared. Always on such flights the planes made one or more descents to cut the inversion at various places. At first considerable difficulty was encountered with the relative humidity element on the aerograph carried by the seaplane, and the records could be accepted only in a general way. Later new hairs were installed and thereafter the readings were considered as trustworthy as those on similar instruments.

Great effort was made to obtain correct readings on all flights. It had been noticed that the temperature traces on the records were frequently inaccurate at the take-off, owing to solar radiation, exhaust engine gases, etc. These records had led to the belief that the lapse rate from the surface to the base often greatly exceeded the dry adiabatic lapse rate, but flights made according to the adopted plan of having the correct temperature of the surface air before the take-off, and then rising very slowly, practically never showed a superadiabatic lapse rate, except for very limited distances. However, the true lapse rate was ordinarily found to equal, or closely approximate, the dry adiabatic. Close observations of the relative humidity pen during flight led to the belief that many of the older humidity records were erroneous, due to the rate of climb and the lag of the humidity element, and showed a rate of fall in the relative humidity above the base greatly in excess of the actual decrease. By rising very slowly and leveling off frequently, it was found that while the relative humidity does fall rapidly it does not usually fall as rapidly as believed from the old records, except where the upper air has come from well inland. In addition to the specific instances given, much time was spent flying along the base, and in and around forming and dissipating clouds. Special conditions were watched for and, when found, flights were made according to the plan which seemed best suited to determine the actual conditions.

The inversion is known to have covered the San Diego-San Pedro area not only on the days of these special flights, but on practically every other day during the summers and autumns of 1928 and 1929.

Careful observations, and aerograph records, during many flights showed that the top of the velo cloud almost always coincides with the base. When clouds are not present the base may be identified by the top of the moist surface stratum which, when viewed from above, has a milky appearance and is characterized by indifferent to very poor visibility near its top. Above the base the air is clear and the visibility good. The surface separating these air masses is so sharply defined a pilot may easily fly with the lower part of the plane in the moist stratum and the top part in the warm air above.

The inversion was identified on these special flights to points 30 to 40 miles south, southwest, west, and west-northwest of San Diego, and inland to the foothills and mountains, by means of the aerograph. On many of these days it was identified by means of the velo cloud and haze layer to points more than 100 miles to sea. The U. S. S. *Lexington*, en route from Honolulu to San Diego in June, 1928, passed under the velo cloud at a point about 200 miles off San Diego. This cloud sheet continued unbroken to the coast. The clouds were absent and the weather conditions entirely different at a point 360 miles offshore.

The top of the well formed velo cloud, and also of the haze layer, is remarkably level over the sea. Both are higher over land during the day, due partly to the contour of the country and partly, no doubt, to the thermal conditions. Little difference could be found in the height of the base a short distance offshore and 30 to 40 miles at sea, although great care was taken in these determinations since it was, and is, believed that the surface stratum is wedge shaped and that the inversion is much lower, and of considerably less magnitude, at a distance of 100 to 150 miles to the west. Several records definitely showed a smaller inversion 30 to 40 miles at sea than a few miles offshore, and a few were believed to show a lower altitude, but the difference was so small the records were not considered conclusive. The heights of the base were always obtained from records made during slow ascent, since it had been found early in this investigation that aerograph readings made during ascent should not be compared with those obtained on descent.

As was to have been expected, it was found that the amount and sharpness of the inversion was less over land than over sea during the day, and that both of these conditions decreased with distance inland.

Many flights were made to determine the lapse rate from the surface to the base in clear weather. On these flights the plane was allowed to remain on the water with the aerograph on the windward wing and in the shade of the upper wing until the temperature trace was steady. This was done to insure that the true air temperature was recorded at the take-off. To overcome instrumental lag, the ascent to the base was made very slowly, as much as 30 minutes having been required to climb 2,000 to 2,500 feet on several occasions. All records obtained during flights of this type show a lapse rate equal to, or closely approximating, the dry adiabatic lapse rate. In a few instances a superadiabatic lapse rate was found for short distances. These flights also showed a gradual increase in relative humidity from the surface to the base. Several theoretical humidity curves were prepared from the Neuhoff Chart for comparison with individual aerograph records. To obtain this curve the current surface humidity was taken and, assuming that the moisture had been thoroughly distributed by turbulence, points were picked off the chart in accordance with the temperatures found at the various altitudes. On some flights the relative humidity traces showed that the water vapor had not been thoroughly distributed, and in every instance the sky remained clear until late at night, although on several occasions clouds began forming in late afternoon, but soon dissipated.

The impression had been gained from many records that the relative humidity fell off very rapidly above the base. In nearly every case where the plane climbed very slowly into the inversion it was found that this falling off in relative humidity is considerably more gradual than had been anticipated, i. e., because of the sluggishness in the instruments, the lower strata above the base had been given credit with a degree of dryness which ordinarily does not exist. This, of course, is what would have been expected had it been known that the velo cloud is caused by convection.

The velo cloud occurs at sea far more frequently than over land, or even along the coast. Observations from planes have shown that, toward the end of a period of clear weather, clouds form far at sea, at least 50 to 100 miles, and spread eastward. It is not unusual to observe a well formed sheet, or bank, of velo cloud far beyond San Clemente Island, 60 miles distant, a day or two before clouds form over, or near, the shore. During normal summer weather, when the days are clear and the nights cloudy, the clouds begin forming over the sea several hours before any develop over land. On many of the brightest days on shore a cloud bank covers the ocean from a point a few miles offshore to a distance of more than 100 miles.

The first indication of the formation of the velo cloud is the appearance of innumerable cloudlets in the topmost part of the moist stratum. When viewed from above these cloudlets resemble little puffballs. They increase rapidly in number and size, merging with one and another, until large globular masses of clouds are formed. These clouds also increase in size and finally merge to form the velo cloud sheet. Observations of the above conditions have been made repeatedly from planes flying along the base. When watched from this level it is seen that the formation of the cloudlets is preceded by the appearance of little lumps on the top of the moist stratum, or haze layer, which, up to this time, has been remarkably smooth and level. In a short time small cloudlets can be seen forming in the lumps and as the plane flies along the base a marked increase in bumpiness can be noticed as it passes through that area. After the cloudlets have grown into the globular masses of clouds, mentioned above, well defined ascending currents can be noticed when flying through them.

The above observations, of course, suggest convection. Although the thermal conditions have been shown to be favorable for convection during late afternoon and night, a more positive confirmation of the idea is found from the fact that, in nearly all of the cases observed, the base rose over the forming clouds, i. e., the cold, moist air rose into the warm air above. This could easily be observed from the milky appearance of the moist air as well as by the clouds themselves. Under certain favorable conditions, namely, when the temperature increased but slowly with altitude above the base, and there was a fair amount of moisture in the warm air, the base was found to be 300 feet higher over a mass of forming clouds than in the surrounding clear areas. Under similar conditions the top of a well formed sheet of velo cloud was observed to rise 300 feet in 5 minutes and another 200 feet during the next 15 or 20 minutes. This observation was made in the late afternoon when the bank was approaching the shore. The base sloped downward from the top of the clouds, which were more than 1,200 feet in depth, to the original base along the coast. Clouds were developing rapidly under the sloping portion of the base, being in the form of small puffballs near the shore, globular masses a little farther at sea, and columns near the edge of the bank.

Some aerograph records show a very rapid rise in temperature and a very rapid decrease in relative humidity above the base. The Neuhoff Chart shows that the base can not rise to any extent under these conditions even though the cloud sheet attains considerable thickness. Since radiation from the top of the moist layer must continue, whether the base rises or remains the same, the convection will continue and, instead of the top of the clouds becoming higher, the base of the sheet will become lower. Many flights have shown the height of the base in the morning to be approximately the same as during the preceding afternoon, and it is not uncommon to observe a very low cloud base in the early morning. There is a peculiar fog condition which occasionally results from the lowering of the cloud base. This condition has been carefully watched in San Diego where the

base of the clouds could be seen to become lower until it obscured the tops of the high buildings, then the lower buildings, and finally rested on the surface and appeared in all respects like true fog. As this occurred at night it was possible to see the base of the cloud as it approached the street lights, and it was observed to be very irregular and ill-defined. Such fogs generally do not last more than two or three hours. When they clear they sometimes do so from the bottom up and again from the top down, i. e., in the former the cloud clears at the surface but continues aloft, while in the latter the top either clears, or descends, until the surface is reached and the sky remains clear the remainder of the night. The latter condition was observed more frequently than the former. If a sharp base is known to be at 1,000 or 1,200 feet, or less, and the relative humidity at the surface somewhat above normal, fog is to be expected that night.

It hardly seems necessary to mention that the presence of a considerable amount of high clouds, either cirro or alto clouds, greatly retards the forming and burning off of the velo cloud. However, this is a fact and must be considered by the forecaster when attempting to answer some of the whens he is asked.

The flights and observations described above were made largely because of the belief that if the inversion and the velo cloud were more fully understood, the explanation of the various types of weather would follow. Although it was impossible to verify many of the following contentions, it is believed that the principles set forth in the preceding paragraphs satisfactorily explain many of the perplexing questions which confront the forecaster along the California coast. Among the most important of these may be mentioned (*a*) the existence of the inversion with deep westerly winds as well as with winds from land; (*b*) why the velo cloud forms; (*c*) why it is typically a night cloud; (*d*) why it occurs over the ocean so much more frequently than over the land; (*e*) why it frequently does not burn off at sea; (*f*) why the base frequently rises during the night; (*g*) why the cloudiness sometimes increases for several days and then decreases during the next several days (occasionally the clouds will disappear entirely within 24 to 48 hours and the resulting clear weather will continue for several days); (*h*) why fog is almost sure to develop along the coast and for several miles inland on nights when the base is less than 1,200 feet high, especially when the temperature above the base increases rapidly; (*i*) why this type of fog clears over the land within a few hours, sometimes from the ground up, but more often "from the top down"; and why a light mist sometimes falls in the early morning during the summer.

It is recognized that the observations made in 1929 are but the beginning of those necessary to solve the riddle of the irregularities of California's regular weather, but it is felt that useful, as well as interesting, information has been obtained. It is seen that the aerograph has become much more helpful to the forecaster because, by means of it, he is supplied with such very useful information, as, the height of the base, the amount and sharpness of the inversion, the humidity above the base, and the lapse rate and distribution of moisture below the base. All of these data are of practical value in forecasting local weather and, in all probability, will become more so as additional facts are learned since, even with the imperfect ideas held during this investigation, the thickness of the morning velo cloud and the height of the base were forecast several times from the afternoon aerograph record and the Neuhoff chart. It is granted that this was largely the result of chance, since the assumptions made were only guesses. Still there appear to be no good reasons why, with additional knowledge, not only the height and thickness of the clouds and the height of the base, but also the other features which are of vital importance to the aviator and navigator will be forecast with confidence and accuracy.

SOUTHERN ARIZONA FLYING WEATHER

By Leon C. Walton

[Weather Bureau Office, Phoenix, Ariz.]

Science and invention have accomplished considerable in recent years to further the cause of aviation. Equipment has been improved and many valuable lessons learned, often at great cost, so that aerial navigation has been stripped of most of its perils. In flying circles, the weather remains a favorite topic but even that has been shorn of its terror, not because we can defy or control the elements, but due to the excellent system of reporting and forecasting conditions as they are and as they will be a few hours or days hence.

No section of the country enjoys "perfect" weather, but southern Arizona is probably as free from weather hazards as is any locality in the United States.

The route selected by the Southern Transcontinental Airline from El Paso, Tex., via Douglas, Tucson, and Phoenix, Ariz., to Los Angeles, Calif., traverses a flat open terrain, with the exception of a low range of mountains near the Arizona-New Mexico boundary, and a scattering of hills, some of which have been dignified by the name of "mountain." Throughout the greater portion of the year, a pilot flying over this territory at an altitude exceeding 1,500 feet is in a realm where the visibility is limited only by the power of his own eye. Haze, smoke, fog, low clouds, and other limiting agents are of such rare occurrence as to be almost negligible. Snow, sleet, and ice are practically unknown, and the only place they could occur would be in the upper reaches over the only range of mountains crossed.

Dense fog, so feared in many localities, seldom obscures the Arizona landscape. It has been observed only 36 times in the past twenty years at the Phoenix Weather Bureau office, and the distribution by months leaves most of the year fog free. December leads with 20; January follows with 11; November supplies 4; and March furnishes the other day with dense fog. Five of the twenty years have had none at all. During the winter months an occasional blanket of smoke partially obscures the city of Phoenix but leaves the airport clear. At Douglas, Ariz., the smoke occasionally cuts the visibility to as little as 3 miles, but is never dense enough to offer a serious handicap to flying, as the "blanket" is not more than 300 or 400 feet in thickness.

Another indication of the excellent visibility is the fact that the beacons between Phoenix and Los Angeles are located about 30 miles apart. East of Phoenix the airway is not yet lighted but when installation is completed the average distance between beacons from Dallas to Los Angeles will be as nearly uniform as possible.

Ceilings are usually unlimited, or at least, sufficient to allow a generous margin of safety. In time of precipi-

tation estimated ceilings less than 1,000 feet have been reported, but the lowest ceiling encountered by a pilot balloon is 1,125 meters, or 3,700 feet.

With fair weather the prevailing condition, flight schedules are seldom interfered with. Occasional unfavorable weather at the coast terminal delays a plane's departure, but cancellations are few. During the eight months of airmail in this section, only about 15 flights have been canceled due to Arizona weather, most of these occurring during February of this year.

In line with its policy of cooperation and expansion, the Weather Bureau inaugurated pilot balloon work at the Phoenix Weather Bureau office in February, 1930, and the data thus obtained played an important rôle in preparing schedules for the air mail which began eight months later.

The upper-air data herewith presented have been prepared from the results of the first year's observations, i. e., to January 31, 1931. Only the regular morning and evening runs have been considered, of which there have been 696 out of a possible 708, or 98.3 per cent. Only 5 of the 12 runs omitted were missed on account of the weather. Surface data are not included in the accompanying tables, being deemed of insufficient value to justify the time necessary for its preparation. The surface wind at the morning observation is light to gentle easterly with surprising regularity, while that at the afternoon run is usually light to gentle variable. The exceptions to both of these generalities would not be sufficient to affect the averages. Four levels have been selected for study, namely: 1,000, 2,000, 3,000, 4,000 meters above sea-level, and it is interesting to note that these levels were reached by 696, 694, 624, and 446 balloons, respectively. Thus, only 70 runs failed to supply data as high as the 3,000 meter level. The large decrease between the 3,000 and 4,000 meter levels is caused by the use of lanterns for the morning observations.

TABLE 1.—*1,000 meters above sea level*

[Velocities in meters per second; fractions omitted]

	Summer				Winter			
	A. M.		P. M.		A. M.		P. M.	
	Number	Average velocity	Number	Average velocity	Number	Average velocity	Number	Average velocity
N	11	2	2	3	7	4	5	2
NNE	2	4	5	2	7	5	4	4
NE	7	3	3	3	10	4	6	2
ENE	7	4	0	0	32	6	6	4
E	8	3	0	0	22	7	14	4
ESE	13	6	7	2	20	6	20	5
SE	9	6	8	4	7	4	7	5
SSE	6	4	4	5	3	5	6	2
S	7	6	5	3	6	8	9	5
SSW	7	3	7	4	7	3	7	7
SW	8	6	13	3	14	4	12	4
WSW	27	5	36	5	6	3	16	4
W	30	4	47	5	12	5	20	5
WNW	15	5	27	4	4	3	18	5
NW	11	4	10	3	3	13	6	3
NNW	9	3	3	2	4	3	7	3

The following tables, numbered 1, 2, 3, and 4, present the results of these 696 observations. The division into summer and winter include April 1 to September 30, and October 1 to March 31, respectively. The first column under each season gives the total number of times the wind blew from the directions indicated regardless of velocity. Otherwise the various headings are self-explanatory. Originally, it was planned to include the wind resultants for each season, but as these data are already on file, by months, at the Weather Bureau offices in both Washington, D. C., and Phoenix, Ariz., available to those who may have special need thereof, this plan was abandoned in favor of the less technical one presented in this paper.

TABLE 2.—*2,000 meters above sea level*

[Velocities in meters per second; fractions omitted]

	Summer				Winter			
	A. M.		P. M.		A. M.		P. M.	
	Number	Average velocity	Number	Average velocity	Number	Average velocity	Number	Average velocity
N	7	2	3	4	11	4	13	6
NNE	6	2	2	2	7	7	11	6
NE	2	2	2	2	6	5	11	7
ENE	5	3	7	3	14	5	13	6
E	8	4	5	2	11	6	13	8
ESE	7	4	6	4	17	6	12	7
SE	10	5	4	4	10	6	3	5
SSE	8	6	9	5	6	8	8	5
S	24	7	17	7	7	7	9	8
SSW	15	7	24	6	10	7	15	6
SW	17	5	23	6	20	5	10	8
WSW	19	6	25	6	9	8	11	7
W	15	4	21	5	7	8	11	7
WNW	14	4	15	5	9	6	8	7
NW	11	5	6	4	14	6	7	5
NNW	8	2	4	5	8	5	9	5

TABLE 3.—*3,000 meters above sea level*

[Velocities in meters per second; fractions omitted]

	Summer				Winter			
	A. M.		P. M.		A. M.		P. M.	
	Number	Average velocity	Number	Average velocity	Number	Average velocity	Number	Average velocity
N	7	5	5	5	8	10	14	11
NNE	6	4	3	4	2	6	12	7
NE	2	4	6	4	7	7	7	5
ENE	2	2	5	3	9	7	13	8
E	5	6	6	4	6	7	12	9
ESE	6	7	8	6	8	6	5	10
SE	4	3	7	4	4	5	5	7
SSE	8	5	13	6	4	6	6	7
S	27	9	18	9	7	10	7	8
SSW	28	9	24	9	6	8	9	11
SW	21	9	34	9	20	9	11	9
WSW	16	10	32	7	10	7	12	11
W	9	4	20	6	13	9	4	9
WNW	2	4	9	4	7	8	14	8
NW	6	5	7	7	12	8	7	9
NNW	3	5	7	4	18	8	14	9

Referring to Table 1, it will be noted that during the summer, the prevailing direction is west, or points immediately adjacent thereto, and in the case of the morning observations, is in striking contrast to surface winds. Experience has shown that these surface easterlies are very shallow, the balloons frequently encountering opposing or cross currents a few seconds after being released. During the winter, this lower stratum of westbound atmosphere is somewhat thicker, extending to the 1,000-meter level with greater frequency. In the afternoon, throughout the year, the western quadrant supplies the greater portion of the winds. The range in velocities is small, so the averages listed are truly representative.

Inspection of Table 2, reveals the fact that the prevailing easterlies in the previous level are caused by conditions more local than general, as their influence apparently barely extends to the 2,000-meter level. That they

are more prevalent in the winter than in the summer would indicate that the temperature is vitally important in their existence. In this higher level we find southwest predominating, although the range is from south to west. This is especially true in the summer, as in the winter the winds are more variable. Velocities are higher and, although the increase is not great in summer, there is a tendency toward stronger winds, particularly in the cooler months of the year.

TABLE 4.—*4,000 meters above sea level*
[Velocities in meters per second; fractions omitted]

	Summer				Winter			
	A. M.		P. M.		A. M.		P. M.	
	Number	Average velocity	Number	Average velocity	Number	Average velocity	Number	Average velocity
N	3	7	9	3	3	7	17	9
NNE	3	10	6	5	3	3	4	11
NE	1	3	4	8	11	7	5	8
ENE	2	6	3	3	2	8	12	9
E	3	6	1	11	0	0	5	8
ESE	2	2	6	6	2	3	3	7
SE	3	4	4	4	0	0	4	4
SSE	5	6	9	5	3	7	2	6
S	5	9	11	10	0	0	6	6
SSW	14	12	16	11	0	0	8	9
SW	14	10	29	9	5	12	10	10
WSW	13	10	26	10	4	15	16	12
W	6	8	14	8	5	19	4	14
WNW	5	7	12	6	5	8	16	10
NW	4	5	4	6	11	14	12	14
NNW	2	6	10	3	8	12	10	15

The conditions found at 2,000 meters extend upward through the other two levels, with an ever improving advantage to the eastbound flier. During the summer the sector south to west prevails, while during winter, the directions are from west to north.

Briefly, then, the fact that Phoenix has a greater number of easterly surface winds does not indicate that the upper currents differ from those over the country in general. On the contrary, we find that the movement is from the western portion of the compass. However, the upper winds cover a wider range of directions than are found to exist in many sections of the United States. This may be due to the location of Phoenix at a point considerably south of the usual paths of the cyclones and anticyclones.

Upper-air investigation has revealed several interesting features of the atmosphere in this region. Surface winds are usually light, and, particularly on hot afternoons, this "stagnation" often extends to considerable altitude. Balloons have been followed to 4,000 meters and 5,000 meters with elevation angles remaining above 60°. Graphs of such runs show every point of the compass.

Estimating ceiling or cloud height.—Most observers learn to associate cloud formations with altitudes, so when one is known, the other can be more readily estimated. Such individuals face a problem in this locality until the acquisition of sufficient data warrants definite estimates. Of the 1,150 balloon runs made to date, cloud altitudes have been ascertained in exactly 100 instances, but these, with 3 exceptions have been confined to 3 cloud types. Strato-cumulus lead in frequency, ranging in altitude above the surface from 1,100 to 4,200 meters, with an average of 2,250 meters. The two remaining types share equally as to frequency but show considerable variation in altitude. Alto-cumulus range from 2,400 to 6,400 meters with an average of 3,700 meters, as compared with an average of 5,400 meters for alto-stratus, which showed a range from 4,000 to 8,000 meters. Comparison with the cloud altitude charts in common use indicates that clouds in southern Arizona average somewhat higher than in other portions of the country.

Everything considered, flying conditions are very favorable in this section. An average of only 41 cloudy days, 39 of which with a measureable amount of precipitation, per year; no ice-forming weather; no snow; very little fog; and very few high winds, 43 miles per hour being a 35-year maximum, are some of the outstanding reasons why this has been designated "the fair weather route." Add to this the favorable upper winds as outlined above, and this locality's desirability as a flying center can be readily appreciated.

DIMINISHING WINTER RADIATION FROM SUN AND SKY AT MADISON, WIS.

By ERIC R. MILLER
[Weather Bureau, Madison, Wis.]

A continuing decrease of the insolation registered at Madison with the Callendar bolometric sunshine recorder was pointed out by Mr. A. F. Piippo (*1*) and the question whether it was due to city smoke or to deterioration of the apparatus was considered by Dr. H. H. Kimball in a note to the same paper. The present paper adds further data and applies statistical methods to their interpretation.

Smokiness in Madison is mostly due to heating, since the city is administrative, educational, and residential rather than industrial. The few industrial plants are located 3 or 4 miles east of the Weather Bureau station, and the prevailing winds are northwest in winter, southwest in summer. The university heating plant with chimney 250 feet high is 1,000 feet south-southwest of the station. Its annual consumption of coal (in tons of 2,000 pounds) in years ending June 30, was:

	Tons		Tons
1912–13	19, 576	1922–23	20, 649
1913–14	20, 489	1923–24	21, 693
1914–15	19, 640	1924–25	21, 076
1915–16	20, 039	1925–26	24, 773
1916–17	22, 986	1926–27	25, 963
1917–18	18, 670	1927–28	28, 463
1918–19	22, 162	1928–29	30, 554
1919–20	20, 429	1929–30	30, 153
1920–21	19, 183	1930–31	29, 446
1921–22	19, 997		

The smoke from this chimney always drifts off in a compact stream before diffusing. The proportion of black smoke has been greatly decreased in recent years by improvements in the furnaces to bring about complete combustion. It is not possible to present similar statistics of the use of coal for domestic heating. A notion of the change is afforded by the census reports of the population

of the tenth ward, which includes the western part of the city beyond the university:

1910	1, 092
1920	3, 664
1930	9, 590

When the sunshine record was begun, anthracite was largely used for house heating. Since then there has been a shift to bituminous and to oil.

Winter being the season of smoke emission, the data from the Callendar sunshine recorder have been separated as follows:

Calories per square centimeter of horizontal surface

December-March	Calories	June-September	Calories	Year	Calories
1911-12	29, 473	1911	58, 025	1911	125, 267
1912-13	26, 267	1912	55, 895	1912	122, 855
1913-14	24, 189	1913	57, 974	1913	122, 818
1914-15	26, 253	1914	57, 808	1914	123, 777
1915-16	25, 200	1915	50, 191	1915	114, 087
1916-17	28, 753	1916	58, 547	1916	125, 072
1917-18	28, 763	1917	55, 167	1917	122, 092
1918-19	23, 240	1918	55, 825	1918	120, 593
1919-20	26, 490	1919	56, 060	1919	116, 857
1920-21	21, 009	1920	56, 949	1920	121, 618
1921-22	25, 004	1921	57, 230	1921	116, 286
1922-23	25, 437	1922	55, 847	1922	118, 434
1923-24	22, 948	1923	52, 638	1923	118, 197
1924-25	23, 814	1924	51, 652	1924	112, 606
1925-26	23, 002	1925	56, 376	1925	119, 234
1926-27	23, 026	1926	52, 542	1926	115, 486
1927-28	25, 629	1927	56, 583	1927	112, 552
1928-29	23, 319	1928	54, 688	1928	119, 015
1929-30	23, 829	1929	56, 009	1929	117, 161
1930-31	21, 525	1930	57, 757	1930	120, 136
Mean	24, 858		55, 689		119, 207

The secular trend of each of these series has been found by fitting regression lines, using the method described by Persons (2), pages 158–160. These equations, in which the coefficient is the rate of change in calories per year, are:

		Per cent per annum	Per cent in 20 years
December-March	$y=-244.3x$	−0. 982	−19. 64
June-September	$y=-77.4x$	−0. 139	−2. 78
Year	$y=-391.4x$	−. 329	−6. 58

Of the annual decrease, 62 per cent occurs in the 4 months December–March.

The method of testing the significance of regression coefficients due to "Student" (**3**), pages 115–124, has been applied to these data with the following results:

	Std. error	t	P.
December-March	73. 5	3. 32	<0. 01
June-September	90. 3	. 86	. 40

where P. is the probability that a random sample will have a value of t falling outside the value found here. The regression coefficient for the summer months is evidently not significant, while that for the winter is highly significant.

Such a change could be brought about by an increase of cloudiness. Eye observations of the cloudiness during daylight hours have been made at Madison (bihourly since September, 1918), and the secular trend of cloudiness is shown by the following:

		Per cent per annum	Per cent in 20 years
December-March	$y=-0.0098x$	−0. 151	−3. 02
June-September	$y=-0.2.64x$	−0. 489	−9. 78

The observed trend of cloudiness is just the opposite of what is required to explain the decrease in the observed radiation.

However, it must be remembered that smoke, haze, and fog are excluded in making the estimate of cloudiness, hence an increase in smokiness should produce a decrease in the recorded cloudiness to the extent that clouds are obscured by smoke.

The hours of bright sunshine, registered by the thermometric sunshine recorder in the same 20 years, show the secular trend indicated by the following equations:

		Per cent per annum	Per cent in 20 years
December-March	$y=-5.05x$	−0. 906	−18. 12
June-September	$y=-.0069x$	−. 00428	−. 09

The percentage change of these data for December–March, agrees remarkably closely with the change in calories. The coefficient of correlation between calories and hours of sunshine for December–March is 0.75, which is less than would be expected from the similarity of secular trends.

Deterioration of the Callendar apparatus is believed by Doctor Kimball (1) page 504, to be indicated by the comparisons that have been made between the Callendar apparatus and the Marvin pyrheliometer. Since the Callendar apparatus registers the vertical component of sun and sky radiation, while the Marvin instrument is exposed normally to the sun's rays, the comparisons are made by shading the Callendar receiver, and reducing the drop in ordinate, trigonometrically. In series of observations made in 1913–1915 and in 1917 the shading of the Callendar instrument was simultaneous with the observations with the Marvin pyrheliometer, with the result that the trace of the recorder had to be interpolated. In 1927, the relatively smooth base line representing sky radiation only, was obtained by shading the Callendar apparatus before and after the pyrheliometer readings. This change of technique introduces some uncertainty into the comparisons. The results obtained vary with the altitude of the sun, so that there is either a variation of sensitiveness of one or other of the two instruments, or the trigonometric relations are not as assumed.

Results of comparisons to the end of March, 1927, were given by Doctor Kimball in the paper referred to. Some 37 additional comparisons were made in 1927. The following tables include all of the comparisons:

Number of comparative observations in each group

1913–1915	15	16	14	3	2	2
1917	10	7	5	4		
1927	10	31	24	14	5	1

Average solar altitude of each group

1913–1915	58. 3	43. 0	29. 8	20. 1	15. 0	14. 3
1917	60. 6	43. 6	30. 2	21. 7		
1927	55. 7	41. 5	30. 5	22. 1	16. 5	12. 6

Average factor (f.) to reduce Callendar to Marvin

1913–1915	0.0346	0.0342	0.0354	0.0380	0.0423	0.0502
1917	.0353	.0354	.0377	.0371	------	------
1927	.0354	.0356	.0358	.0381	.0418	.0489

Standard deviation of the observations of f.

1913–1915	0.0010	0.0018	0.0018	0.0024	0.0017	0.0015
1917	.0011	.0010	.0019	.0038	------	------
1927	.0020	.0013	.0023	.0031	.0051	------

Standard error of the mean f. in each group

1913–1915	0.0003	0.0005	0.0005	0.0017	0.0017	0.0015
1917	.0004	.0004	.0010	.0022	------	------
1927	.0007	.0002	.0005	.0008	.0026	------

Increase of f.

1913–1915 to 1917	*0.0007*	0.0012	0.0023	0.0009	------	------
1913–1915 to 1927	.0008	.0014	*.0004*	*.0001*	0.0005	------
1917 to 1927	.0001	*.0002*	.0019	.0010	------	------

The best value of the change of f. in each column, i. e. the one obtained from the means having the smallest standard error at both beginning and end of the interval, is indicated by italicizing. It will be observed that these changes are mostly smaller than the standard errors of the means on which they are based, whereas the differences should be three times as large as the standard errors to indicate progressive change, with certainty.

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DISCUSSION

It is a source of gratification that further comparisons between the Marvin and the Callendar pyrheliometer in use at Madison cast doubt upon a possible deterioration in the Callendar instrument, which earlier comparisons seemed to indicate. On account of the small number of these comparisons in the different periods compared, this point can not be considered definitely settled, however. It is therefore hoped that additional comparisons may be obtained from time to time.

I may add that similar comparisons that are obtained during nearly every month at Lincoln, Nebr., have not shown an appreciable change in the reduction factor for the Callendar pyrheliometer in use at that station, except on one occasion, when the bridge wire was injured and had to to be replaced.

Mr. Miller's paper shows quite conclusively that the progressive diminution in the annual totals of radiation received at Madison is attributable to the increased smokiness of that part of the city in which the university and the Weather Bureau are located, due to the change from anthracite to bituminous coal for heating dwellings, and an increase in the number of dwellings in the university section of the city. The same thing is true at the American University, District of Columbia, where, also, the depletion is confined to the winter months.—*H. H. Kimball.*

THE FUTURE OF AGRICULTURAL METEOROLOGY

By W. A. MATTICE

[Weather Bureau, Washington, August, 1931]

In these days of overproduction of agricultural products, with a corresponding depression of prices, the thoughts of the Nation turn to the plight of the farmer. There are many experiment stations, experimental farms, and various governmental agencies that are continually advising the farmer what crops to grow and what crops not to grow, but has the weather received full consideration in these opinions? The ever-present alchemist that transmutes base materials into the gold of the ripe wheat, corn, etc., has been scarcely accorded the measure of respect due the vast power wielded. The weather in its effect on agriculture has been scrutinized from afar, as through a long-range telescope, but very little has been accomplished in pursuing the microscopic detail necessary for complete understanding of the underlying principles involved in crop growth. The experimenter in physics, for example, does not attack his problems with the pick and shovel of the day laborer, but with intricate machinery, delicate lenses, accurate micrometers, etc. The comparison is perfectly analogous, for the present-day researches in agricultural meteorology are conducted on a grand scale, a State unit, district unit, or even a country-wide unit. The wealth of detail obtainable on such scales are meager, it is indeed, comparable to the pick and shovel of the day laborer. We might as well supply the archeologist with dynamite alone and expect him to return with the delicate murals, friezes, urns, etc., that are obtained only through infinite patience and careful brushing and screening of minute fragments.

Statistical studies of crop production as related to weather conditions have been and are still being made, with variable results. It is the present experience of investigators that, a series of correlations reaching a coefficient of 0.90, or a little better, is about as good as can be expected with available crop and weather data. However, a coefficient of 0.90 leaves much to be desired, for even with one this high there still remains 43 per cent of the spread between the actual and computed figures to be accounted for outside the data included in the equations. How can this gap be bridged; and is the inadequacy of the data the stumbling block?

The Weather Bureau includes in its meteorological statistics for first-order stations, in addition to temperature and rainfall, the hours of sunshine, direction of the wind, state of the weather, barometric pressure, vapor pressure, relative humidity, etc. Perhaps these, or at least some of them, have important relations to crops, but what material benefit are they when measured on the top of an office building sometimes four or five, or even more, miles from the nearest crops? Again, these first-order stations are widely separated—they are seldom nearer than 50 miles from each other and the various States rarely have over six or seven of them. What variations in the weather occur between them?

The cooperative stations are nearer the crops, being mostly in small towns, or even on farms, in some instances, but they measure only rainfall and temperature once a day and have no self-recording instruments that keep a continuous record. Thus, for these which are more directly applicable, many weather phases are not available.

The crop statistics are even more hazy and generalized, in addition to being relatively inaccessible. We can find easily the estimated yield per acre or total acreage, for the most available data give these figures on a State unit basis, but yields often vary widely in different parts of a State. Local, even in most places county, temperature and rainfall data are available, but what about corresponding yield figures? They are to be had in some individual State publications, but a complete file for one State is difficult to find outside the issuing office and then the series is rarely carried back far enough to be of material value for study purposes. Even if county figures were more readily available, we are again handicapped by the lack of detail, only yield per acre and total acreage being given.

If we are studying corn, for example, when was the crop planted, when did it first appear above ground, when were first leaves seen, when was it knee-high and waist-high, when did ears first appear, silking, tasseling, when in milk, dough, and early roasting-ear stages, when mature? Are there any answers to these important questions? Maybe, locally, at certain experiment stations or elsewhere, but are these records continuous for the same crop under the same cultural practices for 25 years, or more?

The problem at present is to account for the 40 per cent divergence between the predicted and actual yields. Assuming we have carried our study to the 0.90 coefficient mark, and that phenological data in sufficient detail are available for 25 years, what about weather data in corresponding detail? These should be available for at least the neighborhood of the growing crops. At most State experiment stations, unless unusually well equipped, there are maximum and minimum thermometers and a rain gage. These are read at about 4 p. m. or 8 a. m. and the maximum and minimum temperature, set maximum temperature, and total rainfall entered on forms. Where are the details? How much sunshine, what was soil temperature, when did rain occur, how long were temperatures above or below a significant value, what was the relative humidity, rate of evaporation, etc.?

Even if the above questions were satisfactorily answered how can we be sure that we have everything we need? Maybe we need leaf temperature, intensity of solar radiation, plant transpiration, moisture of the soil at different depths, and many other details too numerous to mention.

CONCLUSION

Are we doing everything possible to facilitate the study of crop production in its relation to the weather on a large scale, or even in local areas? There have been some beginnings. Some phenological studies have been made here and there, notably those of Thomas Mikesell, but only in very localized sections. The State weather and crop service of Iowa is at present engaged in collection of phenological data, but the records are still short. There are, at present, no known systematic researches being conducted of the direct relation of weather to crops under field conditions, where detailed weather and crop data are collected, side by side.

We breed high yielding corn, wheat, and oats, drought-resistant corn, rust-resistant wheat, etc., but too little is known of the effect of weather on crops in their various stages of development. We know hot, dry weather hurts wheat at heading time and corn when tasseling and some other generalizations, but that largely comprises the extent of our knowledge at present.

To enable us to know just how the weather is affecting a crop at any time, to forecast crops accurately, and to practice agricultural meteorology as a science and not as an art, we need accurate and comparable data of weather and of crop progress, with the details of various weather phases and of crop development from planting to harvest accurately observed and recorded on the ground.

TOR BERGERON'S ÜBER DIE DREIDIMENSIONAL VERKNÜPFENDE WETTERANALYSE[1]

By ERIK BJORKDAL

[Translated from German text by Andrew Thomson]

Translator's note.—This large and important work of 110 pages (31 by 23 centimeters) with 6 plates and 25 figures written by Doctor Bergeron of the Norwegian Meteorological Office at Oslo constitutes the most important recent summary of the technique of the Norwegian School of Meteorology.

Due largely to the absence of definite guidance on how to locate "fronts" on the weather map, considerable misunderstanding of polar front methods has arisen. Prof. J. Bjerkness's memoir[2] on Practical Examples of Polar Front Analysis, written in 1926, deals with specific cases of fronts passing over the British Isles, whereas Doctor Bergeron discusses the general principles of frontology equally applicable to Europe and to North America.

The following illuminating review by Doctor Bergeron's colleague indicates the field covered by Doctor Bergeron's extremely valuable and suggestive book which is marred for English readers by an involved style of sentence structure:

This work gives the first systematic exposition of the analytical methods of the so-called Bergen School of Meteorology. It discusses the existence and formation of tropospherical air masses and air separations, as well as their decisive importance for weather. Until further empirical investigations have been carried out the results hold only during the winter season over North America, north Atlantic, and western Europe.

The author first attacks the view which has often been advocated that the chief seat of pressure variations and weather changes may be sought in the substratosphere. He brings forward various plausible reasons for believing that the extratropical transformations of energy have their seat essentially in the troposphere and even in its lower half. There the weather actually displays itself.

The study of the structure of the troposphere is thus of fundamental importance. Already before the work of the Bergen meteorologists, various investigators had deserted pure isobaric geometry and realized there was a battle between air masses. But none of them was lead from their theoretical considerations to the daily weather map and no one realized that the boundary surfaces were entities of which the properties and dynamics

[1] Bergeron, T.: Ueber die Dreidemensional Verknüpfende Wetteranalyse, I. Teil. Geophys. Pub., Oslo, vol. 5, No. 6, 1928.
[2] Geophysical Memoir No. 50, British Meteorological Office, London, 1930.

could be studied. This was first done in the works of J. Bjerknes and H. Solberg.

The complete 3-dimensional weather analysis can be attained only by the utilization of the inner connections which exist between the fields of the meteorologist elements and between their singularities. Two-dimensional fields may be constructed from the ordinary continuously recorded data, but one must consider that the local and individual derivatives of the elements, without further information, can not be interchanged. The registrations show in addition that linear interpolation between adjacent air particles can be employed only within a homogenous air mass. With the passing of a front, linear interpolations can be employed no longer.

The analysis should be based only on representative observations. Representative temperature data should fulfill the condition that the mean vertical temperature gradient has approached already its characteristic value in the free air for the air mass under consideration. Frequently nonadiabatic influences disturb the temperatures at the earth's surface, so that they cease to be representative. Already in 1919 the Bergen school had adopted the view that temperatures of the free air and of mountain peaks should have special weight.

If the source and path of an air mass are known, then the internal changes during its transport can be estimated. Starting with the conditions in the area of origin one can judge the value of the characteristics of the air mass and of their height distribution along its path. In the first place, the approximately conservative properties must be considered; that is, those properties of which the intensity in any individual element of mass remain practically constant. Certain thermal and chemical properties belong to these classes.

Potential temperature and vertical temperature gradient are, with certain reservations, conservative. Admixtures of suspensions of particles so fine that they take part almost completely in the air movement presumably belong to the conservative chemical properties. These produce an opalescent turbidity of the air which has been investigated by the author at Swedish and Norwegian stations. Here the essential part of the pure opalescent turbidity arises out of desert or continental dust which has been transported northward from the subtropical high-pressure zone.

The breaking up of the troposphere into great currents appears markedly in winter through the striking great-scale features of the pressure field. In these currents the air masses concerned will be subjected to two fundamentally different types of exterior influences.

One mass which moves over the ocean toward an always increasing warmer understratum will increase its entropy. On the other hand, an air mass which goes over the ocean with ever colder surface temperatures loses entropy. Thus two chief types of air mass are probable, which are designated by the terms "cold-air mass" and "warm-air mass." Of these chief types, "polar air" and "tropical air" are the most important representatives.

The cold air mass will be formed mostly in polar areas and in winter generally in the continental anticyclones of higher latitudes. It is in its area of origin, cold, dry, and especially at lower levels stabile. It moves in general Equatorward so that the difference between air temperature and sea temperature is negative. The entropy supply exerts its greatest effects on the lowest layers of the air, which experience an increase of potential temperature and of vertical temperature gradient.

Experience has shown that after the cold air mass has traveled for about 200 kilometers over distinctly warmer ocean it has already taken up sufficient moisture that its humid air content is brought over the condensation level. Cu-Nb clouds with anvil form and even slight precipitation occur. On account of lively up and down movements definite clearings and pieces of clear sky may be observed. Because of the great turbulence any fog which happened to be present can only persist in small zones where it appears below a temporary calm. The system of hydrometeors can be characterized as belonging to shower air.

The warm air mass is usually generated in the oceanic highs of the Tropics and in summer over every great snow-free and ice-free land surface. It is in its area of origin warm—in the case of continental air also dry—and stratified approximately according to its radiation equilibrium. On the average it moves poleward so that the difference in temperature of the air and the land or ocean over which it travels is positive or zero. The entropy losses affect most strongly the lowest layers, which experience a reduction of vertical temperature gradient. The upward transport of humidity will be a minimum and the slight heat transport will be directed downward. The potential temperature will exhibit slight change.

Various cooling effects give rise to stratiform cloud and to fog, which on account of the small convection persists without dissipation. The warm air mass exhibits pervading bad visibility because of the tendency for fog formation. The system of hydrometeors can be characterized as belonging to drizzle air.

The direct empirical grounds for the properties of the air masses described can be supplied only through exhaustive synoptical research. This will be the work of the second part. Part I already deals statistically with the relation between the probable air masses and the difference between air and sea temperatures, vertical temperature gradient, and hydrometeors.

The temperature difference is investigated from the data of Dutch lightships and the dependence on origin of air mass confirmed.

The aerological airplane ascents at Berck, near Boulogne, 1918–19, give good reasons for believing that shower air and drizzle air are of fundamentally different structure. For the same surface temperature, there was a temperature difference of 9° C. of the two masses at 3 kilometers height. In drizzle air the chief condensation layer was about 1 kilometer above the ground, above which the humidity fell rapidly. In shower air no sharply bounded chief layer of condensation existed, while above 3 kilometers the relative humidity was distinctly greater than in drizzle air.

Several observations in Berck support the author's theory that the coming together of thick and compact water clouds with layers of permanent ice crystals is, except for drizzle, a chief source for all usual precipitation.

Conclusions may be deduced from the kind of hydrometeor regarding the thermodynamics and dynamics of the classified air mass. In the author's opinion the following threefold grouping of hydrometeors recommends itself for adoption in international observation technique:

(1) Ordinary rain (snow)—Either ordinary raindrops (snowflakes) or scanty fine droplets.

(2) Drizzle—Exclusively very fine droplets with great number of drops per unit volume.

(3) Showers—Sharp intermittency of precipitation and medium cloud cover.

From a consideration of the mode of formation of cold air and warm air masses it could be expected that a positive difference between air and sea temperatures corresponds to drizzle and a negative difference to shower air. The author has investigated this rule from 620 observations taken at Thorshavn and found that the rule holds good without exception for differences greater than 0.5° C. For smaller differences no definite contradiction could be established. It thus follows that accurate measurements of air and sea temperatures at all international island and ship stations and their report to 1/10° C. or 1/5° F. have great importance for practical weather analysis.

The investigations of the author on horizontal visibility in Scandinavia confirmed the hypothesis that the opalescent turbidity of the warm air mass is notably greater than of the cold air mass.

From a previous work of the author (Wellen und Wirbel, Leipzig, 1924) it is known that surfaces of equal entropy (isentropic surfaces) of the cold mass are inclined upward toward the pole, while in the warm air mass they are almost horizontal. Thus is follows, as is later discussed in detail, that the cold mass easily becomes heterogeneous while the warm air mass with horizontal isentropic surfaces is among the most homogeneous masses of the atmosphere.

By means of aerological data from Holland and Spiegглitzer, Schneeberg, the existence of at least two separate air masses is statistically indicated. The potential temperature has at any level two pronounced frequency maxima which correspond to polar air and tropical air.

When two air masses each uniformly homogeneous approach each other nearer than about 1,000 kilometers, the area between them no longer fulfills the conditions of a homogeneous air mass. A frontal zone occurs which can gradually sharpen to a front. Fronts are narrow inclined transition zones of the same vertical extent as the air masses. It is essential that the difference of the values on both sides of the front of at least one of the independent elements (temperature, pressure, wind, humidity) is so great that it has an appreciable effect on the great scale dynamics (of the air mass).

In the troposphere, fronts are continuously produced and destroyed. The author has called these processes frontogenesis and frontolysis. Kinematic frontogenesis consists in the coming together of the equiscalar surfaces of an element through the motion of the individual particles.

In dealing with air masses which are not too extended the field of movement can be treated as linear. The movement itself may be resolved into four partial fields consisting of a translation, a rotation, an expansion, and a deformation. Only through the deformation movement can two particles essentially approach or separate from one another.

As no essential change of volume can occur, a deformation is undergone either as an extension along the principal axis and a contraction along both secondary axis or as a contraction along the principal axis and an extension along the secondary axis. Material particles which at one time form a plane surface will always form a plane surface which during movement alter only their orientation and their distance from the field's center. In a 2-dimensional field the surfaces rotate so that they will ultimately be perpendicular to the axis of greatest contraction.

A symmetrical deformation field with vertical axis produces the following effects—the extension of the principal axis causes dissolution of horizontal inversion zones while contraction brings sharpening.

A 2-dimensional half deformation field with one horizontal axis and an axis directed obliquely upward causes frontogenesis and dissolution of inversions. Contraction along the horizontal axis causes frontolysis, while expansion causes inversion formation.

The choice of entropy surfaces as equiscalar surfaces presupposes advective frontogenesis. Thus from the beginning the entropy surfaces are inclined and advection comprises a permanent deformation-field of which the axis of contraction can not be directly vertical. It thus follows, as has been previously pointed out, that in the warm air mass where the isentropic surfaces are almost horizontal almost no frontogenesis occurs; in the cold mass where they are somewhat inclined, weak frontogenesis; and in frontal zones where they are considerably inclined there is effective frontogenesis.

The general circulation of the earth's atmosphere is divided into several partial circulations. They can be considered as a system of vertical wheels and of horizontal wheels. The hyperbolic points between the wheels are the centers of the deformation fields in the foregoing sense. Frontogenesis and frontolysis develop in the areas between the parts of the general circulation. The effect of the vertical wheels and horizontal wheels will alternately strengthen and oppose each other.

When the general circulation works frontogenetically, areas occur where by preference fronts are formed. The favored frontal zones run east and west. In the intermediate zone where the vertical opposes the horizontal circulation, the resulting effect will be mostly frontolysis so that the air exchange between pole and Equator can go on unhindered.

Doctor Bergeron's book is conceived as the principle introduction to the problem of air masses and front formation. The use of the results for investigating the relations actually occurring in the troposphere will be shown in Part II. The wish may be expressed that we may not need to wait long for this continuation.

ON PERIODICITY IN SERIES OF RELATED TERMS [1]

By Sir Gilbert Walker, F. R. S.

SUMMARY

In 1927 Yule developed the idea that a series of numbers $u_1, u_2, \ldots, u_n$ expressing the condition of a physical system, such as successive annual sun-spot numbers, might be regarded as due to a series of accidental disturbances from outside operating on some dynamical system with a period or periods of its own, probably subject to damping. The consequent oscillations would vary both in amplitude and in period. In this paper it is shown that if Yule's equation defining the relationship between successive undisturbed terms of the u series is

$$u_x = g_1 u_{x-1} + g_2 u_{x-2} + \ldots + g_s u_{x-s},$$

then, provided n is large, a similar equation holds very approximately between successive values of r_p, the correlation coefficient between terms of u separated by p intervals, i. e.,

$$r_x = g_1 r_{x-1} + g_2 r_{x-2} + \ldots + g_s r_{x-s}.$$

[1] On periodicities in series of related terms, Proc. Roy. Soc. Series A, vol. 131, No. 818, pp. 518-532.

* The subject is treated from the mathematical viewpoint and since no one's views are entitled to greater consideration than those of Sir Gilbert we print in his own words the summary of his conclusions.—Ed.

Thus the graph expressing the r_p's, which is much smoother than that of the u's, may be used to read off the character of the natural periods of the u's; further various relationships are found between the amplitude of the corresponding terms in the Fourier periods and those of the correlation coefficients.

The analysis is illustrated by applying it to the quarterly values of pressure at Port Darwin, a key center of world weather, which proves to have a strong persistence and to show evidence of not very strongly developed periods of about 34½ months and of about four times this length or 11½ years; the series of data is not long enough to settle whether the former oscillations are damped and are free oscillations, but the latter appear to be imposed from without and are presumably solar in origin.

WULF AND MELVIN ON THE EFFECT OF TEMPERATURE UPON THE ULTRA-VIOLET BAND SPECTRUM OF OZONE AND THE STRUCTURE OF THIS SPECTRUM

The ultra-violet absorption of ozone in the region 3400–2300 Å consists of a large number of bands appearing against a background of continuous absorption. The effect of temperature upon this spectrum has been studied over the range −78° to 250° C. A definite though small effect has been observed. Grossly it manifests itself as an increase in contrast with decreasing temperature. Photometric results show this to be chiefly a decrease in absorption between the band edges, all of the bands appearing to come from normal vibrational levels of very low if not the lowest energy. Though somewhat diffuse, the bands tend to degrade to the red. The observed influence of temperature can be explained as the decrease of intensity in the higher rotational absorption of the bands, and possibly also in the continuous background, with decreasing temperature. Discontinuities in the intensity relations and the regular spacing of certain of the bands have led to a partial vibrational analysis indicating two active vibrational degrees of freedom in the excited electronic state. The observed change in the absorption with temperature may effect somewhat the estimates which have been made of the amount of ozone existing in the upper atmosphere.—(*Bulletin of the American Physical Society, Program of the Washington Meeting, April 16, 1931, volume 6, No. 2, page 42.*)

FATHER E. GHERZI, S. J., ON THE WINDS AND UPPER AIR CURRENTS ALONG THE CHINA COAST AND IN THE YANGTSE VALLEY[1]

The publication under review comes from the well known observatory of Zi-Ka-Wei, near Shanghai, organized more than half a century ago and operated in the interest of meteorology with special application to storm warnings for navigators of the adjacent seas. The present publication has its special appeal to navigators of the air in the Far East.

The upper air data available to Father Gherzi are far too few to afford definite reuslts; nevertheless those at hand in connection with the movement of the clouds and the surface winds, statistics of which are abundant, enable the author to present a picture of free air conditions that is of much value in air navigation.

His pilot-balloon material consists of ascents made at Chefoo by the U. S. S. *Jason* in May, June, July, August, and September, 1928; pilot-balloon ascents were also contributed by H. M. S. *Argus* at Shanghai made in October, November, and December, a few ascents in each month. These ascents though few in number serve to indicate the direction and force of the winter monsoon winds along the China coast. As might be expected these winds are due essentially to the presence and the intensity of the so-called Siberian cold season anticyclone; the center of which may be over the Province of Shantung in China, rather than in Siberia. Father Gherzi concludes that for winter monsoon days the winds aloft back with increase in altitude above the surface. Data for the summer monsoon are much too few to permit the drawing of definite conclusions. Conditions during the summer monsoon are much less ready than during the winter monsoon.

The statistical data of surface winds are given in very great deatil for a number of stations on the China coast. The 240 quarto pages comprised in the report are mostly taken up with data of cloud movement and surface air movement printed in detail for a number of years of record. Appropriate charts and diagrams add to the interpretation of the statistics. The price of the work is $4.50.—*A. J. Henry.*

[1] The winds and upper air currents along the China coast and in the Yangtse Valley Zi-Ka-Wei Observatory, Shanghai, 1931.

RESULTS OF RAINFALL OBSERVATIONS IN WESTERN AUSTRALIA[1]

The present volume is the fifth of a series published by the bureau. Volumes for Victoria (1910), N. S. Wales (1914), Queen Island and South Pacific (1913), South and North Australia (1917) have already been published. The last volume, discussing Tasmania, is under preparation. As soon as the series is completed supplementary volumes are to be published to bring the early issues up to date.

The present volume contains a concise history of the rainfall and weather of western Australia, from the time records began up to the end of 1927. A few of the records go back as far as 1877 and even earlier. The number of stations is 1,374.

The work contains a written tabular history of rainfall by months from 1877 to 1926; a short note on the climate of western Australia; a discussion of the relationships between wheat yield and rainfall; a record of notable meteorological events in the State, e. g., auroræ australis, bush fires, earthquakes, floods, etc. These occupy half of the volume. The second part of the volume contains the annual rainfall data of all stations in western Australia. At the end of the volume annual rainfall maps for western Australia from 1886 to 1927 are published, and also a revised annual rainfall map of Australia.

This publication is valuable to all those interested in the climate of western Australia, but especially to agriculturists and sailors. It lacks a thorough discussion of the rainfall and weather but it is an excellent source book containing the available data and written history of the weather in western Australia. Especially valuable are the numerous maps and charts included in the 387 pages of text.—*Sigismond R. Diettrich.*

PROF. ALEXANDER McADIE RETIRES FROM BLUE HILL OBSERVATORY

After sabbatical leave for the first semester of the coming academic year, Alexander McAdie, Abbot Lawrence Rotch professor of meteorology, Harvard University, and director of Blue Hill Observatory, will become professor emeritus.

[1] Results of rainfall observations made in western Australia, Commonwealth of Australia, Bureau of Meteorology, under the direction of H. A. Hunt, Commonwealth meteorologist, 1929, p. 387.

In recognition of his long and distinguished service and his notable contributions to man's knowledge and understanding of the weather, a dinner was given Professor McAdie on June 11 by the Harvard visiting committee to Blue Hill Observatory, and a silver bowl was presented to him and Mrs. McAdie as a token of the committee's affection. Professor and Mrs. McAdie will make their home at Hampton, Va.—(*Bulletin American Meteorological Society August-September, 1931, p. 158.*)

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SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS DURING JULY, 1931

By HERBERT H. KIMBALL, Solar Radiation Investigations

For a description of instruments employed and their exposures, the reader is referred to the January, 1931, REVIEW, page 41.

Table 1 shows that solar radiation intensities averaged above the normal intensities for July at Madison, and close to the July normals at Washington and Lincoln.

Table 2 shows an excess in the total radiation received on a horizontal surface as compared with the normal amounts for July at Madison and Fresno, and a deficiency at all other stations for which normals have been computed.

Skylight polarization measurements obtained on 8 days at Madison, give a mean of 60 per cent with a maximum of 70 per cent on the 24th. At Washington, measurements obtained on 4 days give a mean of 53 per cent, with a maximum of 58 per cent on the 27th. These are close to the corresponding July averages for both stations.

TABLE 1.—*Solar radiation intensities during July, 1931*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
July 8	17.37				0.72						18.59
July 11	14.10			0.78	0.90	1.26					10.97
July 14	19.23				0.82	1.14					20.57
July 15	17.96				0.74						17.96
July 22	13.61				1.09	1.32					13.13
July 23	13.61			0.78	0.99	1.17					13.61
July 25	13.13			0.76	0.98	1.25					8.81
July 27	16.79		0.63	0.80	1.00	1.18					10.97
July 28	18.59				0.82	1.14					14.60
July 29	19.89			0.84	0.88						14.60
Means			(0.63)	0.79	0.90	1.21					
Departures			−0.04	+0.02	±0.00	+0.02					

[1] Extrapolated.

TABLE 1.—*Solar radiation intensities during July, 1931*—Contd.

Madison, Wis.

	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Date	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e.	5.0	4.0	3.0	2.0	1.0	2.0	3.0	4.0	5.0	e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
July 1	17.96		0.54	0.69	0.85	1.12					16.79
July 6	12.24		1.01	1.12	1.25	1.39	1.14	0.95			10.51
July 7	9.47					1.44	1.17	0.94			6.76
July 8	10.21	0.85	0.91	0.99	1.16	1.40					7.57
July 9	8.81	0.81	0.94	1.02							9.83
July 10	6.27					1.36					7.29
July 11	8.81				0.96						7.87
July 14	16.20			0.74	0.91						16.79
July 15	15.65					1.14	0.91	0.71			17.37
July 16	15.65		0.73	0.87	1.04						16.20
July 18	10.59					1.45					9.14
July 21	10.59					1.23					10.59
July 22	10.97					1.39	1.16	1.03			9.83
July 24	10.59		0.92	1.06	1.23	1.42	1.10	0.95	0.77		6.76
July 25	10.97			0.92	1.04						9.83
Means		(0.83)	0.84	0.93	1.06	1.33	1.10	0.92	(0.77)		
Departures		+0.12	+0.04	+0.02	±0.00	+0.05	+0.08	+0.01			

Lincoln, Nebr.

Date	75th mer. time	5.0	4.0	3.0	2.0	1.0	2.0	3.0	4.0	5.0	Local mean solar time
July 13	14.60					1.28	1.02	0.81	0.67		17.37
July 14	14.60		0.65	0.78	0.98	1.23	0.94	0.75			17.37
July 16	17.37			0.93	1.14	1.36					17.37
July 20	13.13						1.16	0.97	0.80		11.38
July 21	12.24			0.93	1.13	1.35					11.38
July 23	11.38					1.36	1.15	0.99	0.84		9.47
July 24	10.97		0.84	0.96	1.10						9.14
July 25	12.68		0.77	0.85	1.04	1.21	1.07	0.88	0.73		12.24
July 27	10.23		0.72	0.85	1.06	1.30	1.00	0.81	0.64		17.96
Means			0.74	0.88	1.08	1.30	1.06	0.87	0.74		
Departures			-0.04	-0.01	±0.00	-0.02	±0.00	-0.01	+0.01		

TABLE 2.—*Total solar radiation (direct diffuse) received on a horizontal surface*

[Gram-calories per square centimeter]

AVERAGE DAILY TOTALS

Week beginning—	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Pittsburgh	Gainesville	Fresno	La Jolla	Miami	New Orleans
1931	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
July 2	418	533	507	424	316	709	453	464	726	360	604	403
July 9	475	542	549	406	403	655	442	[1] 287	754	387	589	272
July 16	444	587	527	406	336	624	393		708	345	564	349
July 23	583	574	607	464	415	455	550	440	619	423	593	279
DEPARTURES FROM WEEKLY NORMALS												
July 2	-84	+1	-71	-14	-97	+48	-31	-14	+12	-96		
July 9	-11	+10	-23	-19	+1	-37	-39	-205	+46	-73		
July 16	-300	+72	-41	-10	-60	-56	-83		+8	-123		
July 23	+97	+74	+62	+65	+17	-186	+48	-165	-59	-22		
Accumulated departures on July 29, 1931	+1265	-3192	-77	-1169	-1190	-1063	-1863	-2823	-266	-4872		

[1] 5-day mean.

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, Superintendent United States Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, Perkins, and Mount Wilson observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, includin gspots and groups is given for each day in the last column]

Date	Eastern standard civil time		Heliographic Diff. long.	Longitude	Latitude	Area Spot	Group	Total area for each day
1931	h	m	°	°	°			
July 1 (Naval Observatory)	10	50	-52.0	74.4	+6.0		154	
			-42.0	84.4	-10.0	62		216
July 2 (Naval Observatory)	11	57	-35.0	77.6	+5.0		77	77
July 3 (Naval Observatory)	10	56	-22.0	77.9	+5.0		77	77
July 4 (Mount Wilson)	12	45	-13.0	72.6	+5.0		16	
			0.0	85.6	-8.0		64	
July 5 (Naval Observatory)	10	48	-3.0	70.5	+5.0		31	
			+11.0	84.5	+6.0		31	62
July 6 (Naval Observatory)	13	22	-31.0	27.8	+8.0	3		
			+4.0	62.8	+9.0		31	
			+27.0	85.8	+5.0		62	96
July 7 (Naval Observatory)	11	2	-62.0	344.9	-21.0		62	
			-39.5	7.4	-9.0		93	
			+5.0	51.9	+11.5		31	186
July 8 (Naval Observatory)	11	13	-78.0	315.6	-13.0		31	
			-50.0	343.6	-22.0		62	
			-25.0	45.6	-9.0		108	
			+12.0	45.6	-3.0	15		216
July 9 (Perkins Observatory)	13	30	-83.0	296.0	-5.0	100		
			-79.0	300.0	+1.0	93		
			-29.0	350.0	-11.0	93		286
July 10 (Naval Observatory)	16	32	-50.0	314.2	-11.5		77	
			-21.0	343.2	-21.0	15		
			-8.0	356.2	-19.0	15		
			+7.5	11.7	-8.0		77	184
July 11 (Naval Observatory)	10	43	-38.0	316.1	+12.0		31	
			+3.0	357.1	-20.0	6		
			+19.5	13.6	-8.0	15		52
July 12 (Mount Wilson)	11	50	-24.0	316.3	-12.0	16		
			-8.0	332.3	+5.0			
			+15.0	355.3	-19.0		44	
			+33.0	13.3	-8.0		36	101
July 13 (Naval Observatory)	10	58	-10.5	317.0	-12.0	9		
			-0.1	327.4	+0.5	6		
			+4.0	331.5	+15.0	3		
			+25.0	352.5	+17.0	3		
			+30.0	357.5	-20.0	3		
			+49.0	16.5	-7.5	6		30
July 14 (Naval Observatory)	11	35	-55.0	258.9	+12.0	3		
			-46.0	267.9	+17.0	3		
			+4.5	318.4	-12.0	3		
			+7.5	321.4	+13.0	3		
			+16.0	329.9	-16.0	3		
			+43.0	356.9	-19.5	6		
			+65.0	18.9	-8.0	9		30
July 15 (Naval Observatory)	10	53	-13.0	288.1	-16.0	3		
			+12.0	313.1	-15.0	3		
			+16.0	317.1	+9.5	3		
			+18.0	319.1	-13.0	9		18
July 16 (Naval Observatory)	10	58	+29.0	316.8	-8.0	6		6
July 17 (Naval Observatory)	10	41	+7.5	282.3	+8.0		9	9
July 18 (Naval Observatory)	10	32	No spots					
July 19 (Naval Observatory)	10	55	No spots					
July 20 (Naval Observatory)	10	54	No spots					
July 21 (Naval Observatory)	10	41	-62.0	159.8	+7.5		31	31
July 22 (Naval Observatory)	11	6	-49.5	158.9	+8.0		45	45
July 23 (Naval Observatory)	10	56	-33.0	162.2	+8.0		15	
			-14.0	181.2	-4.0	6		
			-9.5	185.7	+2.5	6		
			-0.5	194.7	+23.0		22	49
July 24 (Naval Observatory)	13	48	-19.5	160.9	+6.5		15	15
July 25 (Naval Observatory)	10	40	No spots					
July 26 (Naval Observatory)	10	50	-60.0	75.6	+7.0		31	31
July 27 (Naval Observatory)	10	49	-62.0	80.4	+7.0	31		31
July 28 (Naval Observatory)	10	45	-52.0	77.2	+6.0		62	
			+40.0	169.2	-1.5	15		77
July 29 (Naval Observatory)	10	50	-43.0	72.9	+12.0	9		
			-38.0	77.9	+7.0	37		
			+59.0	174.9	-7.0	6		52
July 30 (Naval Observatory)	10	36	-25.0	77.8	+8.0		108	
			-18.0	84.8	-6.0		62	170
July 31 (Naval Observatory)	10	50	-11.0	78.5	+7.0		93	
			-3.5	86.0	-6.0		77	170
Mean daily area for July								77

PROVISIONAL SUN-SPOT RELATIVE NUMBERS FOR JULY, 1931

[Data furnished through the courtesy of Prof. W. Brunner, University of Zurich Switzerland]

July, 1931	Relative numbers	July, 1931	Relative numbers	July, 1931	Relative numbers
1	22	11	35	21	Ec 7
2	23	12	26	22	10
3	23	13	30	23	8
4	19	14	23	24	8
5	a 19	15	8	25	8
6	16	16	7	26	0
7	Ec —	17	8	27	Ec 7
8	35	18	7	28	9
9	28	19	0	29	Ec 22
10	Mac 48	20	0	30	23
				31	23

Mean: 30 days=16.7.

a=Passage of an average-sized group through the central meridian.
b=Passage of a large group or spot through the central meridian.
c=New formation of a center of activity: E, on the eastern part of the sun's disk; W, on the western part; M, in the central zone.
d=Entrance of a large or average-sized center of activity on the east limb.

AEROLOGICAL OBSERVATIONS

[The Aerological Division, W. R. GREGG, in Charge]

By L. T. SAMUELS

During July the Weather Bureau began daily airplane observation flights at Chicago, Cleveland, and Dallas and continued kite observations at Due West and Ellendale. The mean monthly free-air temperatures and relative humidities for these stations and those of the Navy are shown in Table 1. A comparison of these data with the normals based on nearby kite stations shows that the free-air temperatures were mostly above normal at all stations. Relative humidities were close to normal at all stations and vapor pressures were in general agreement with temperatures, i. e., above normal.

The resultant winds for the month were variable and light at the ground level. (Table 2.) At the 1,000-meter level the highest resultant velocities were found over the southern Plains States where they reached 8 meters per second with a strong southerly component. An easterly component persisted to 5,000 meters over Brownsville, Dallas, Key West, and Phoenix.

The superiority of airplanes over kites with respect to heights reached and regularity of flights is well brought out in Table 3 which shows the average and maximum heights reached and number of flights made.

TABLE 1.—*Mean free-air temperatures and humidities obtained by airplanes (or kites) during July, 1931*

TEMPERATURE (°C)

Altitude (meters) m. s. l.	Chicago, Ill.[1] (190 meters)	Cleveland, Ohio[1] (245 meters)	Dallas, Tex.[1] (149 meters)	Due West, S. C.[2] (217 meters)	Ellendale, N. Dak.[2] (444 meters)	Hampton Roads, Va.[3] (3 meters)	Pensacola, Fla.[3] (2 meters)	San Diego, Calif.[3] (9 meters)	Washington, D. C.[3] (2 meters)
Surface	20.0	19.3	24.8	27.2	21.4	26.9	26.3	24.0	25.0
500	21.8	20.7	25.9	24.5	20.9	24.2	24.6	19.9	24.5
1,000	21.4	20.8	24.7	22.1	19.2	21.8	22.0	23.0	22.8
1,500	18.3	18.1	22.1	18.9	17.0				
2,000	15.1	15.1	19.2	15.5	14.3	15.3	16.0	21.0	16.7
2,500	11.9	12.3	16.0	11.9	11.3				
3,000	8.8	9.8	12.8	8.8	8.7	10.1	9.7	13.0	10.6
4,000	2.6	4.4	5.9	2.8	2.3		3.2		4.8
5,000	−3.8	−1.1	−0.3		−5.5		−1.4		−1.4
6,000		−6.6							

RELATIVE HUMIDITY (%)

Altitude (meters) m. s. l.	Chicago	Cleveland	Dallas	Due West	Ellendale	Hampton Roads	Pensacola	San Diego	Washington
Surface	82	85	76	75	62	77	89	70	75
500	64	73	70	75	62	71	83	82	66
1,000	56	60	65	71	59	65	74	55	59
1,500	60	63	65	71	57				
2,000	59	66	62	70	54	63	67	43	65
2,500	53	62	58	70	53				
3,000	51	55	56	70	49	49	65	50	58
4,000	44	46	58	50	49		54		54
5,000	36	46	53		63		49		40
6,000		45							

[1] Airplanes (Weather Bureau). [2] Kites. [3] Airplanes (Navy).

TABLE 2.—*Free-air resultant winds (meters per second) based on pilot-balloon observations made near 7 a. m. (E. S. T.) during July, 1931*

Altitude (meters) m. s. l.	Albuquerque, N. Mex. (1,528 meters) Direction	Velocity	Brownsville, Tex. (12 meters) Direction	Velocity	Burlington, Vt. (132 meters) Direction	Velocity	Cheyenne, Wyo. (1,873 meters) Direction	Velocity	Chicago, Ill. (198 meters) Direction	Velocity	Cleveland, Ohio (245 meters) Direction	Velocity
	°		°		°		°		°		°	
Surface	N 65 E	0.6	S 45 E	0.8	S 1 W	2.8	N 68 W	2.4	N 70 W	0.3	S 17 W	1.7
500			S 22 E	7.3	S 36 W	4.1			S 74 W	3.6	S 78 W	3.4
1,000			S 23 E	7.9	S 89 W	4.1			S 78 W	4.4	N 71 W	5.3
1,500			S 29 E	6.6	N 60 W	5.4			N 86 W	5.4	N 68 W	6.3
2,000	S 18 E	2.7	S 40 E	5.8	N 69 W	6.8	N 78 W	3.9	N 84 W	5.8	N 76 W	7.1
2,500	S 11 W	2.6	S 49 E	5.4	N 65 W	7.5	W	3.4	N 78 W	6.3	N 82 W	7.0
3,000	S 57 W	1.4	S 57 E	4.4	N 72 W	8.1	N 84 W	3.5	N 71 W	5.9	N 80 W	6.4
4,000	N 9 W	2.0	S 84 E	2.7	N 87 W	6.6	N 76 W	4.0	N 56 W	6.9	N 58 W	6.7
5,000	N 36 E	4.0	N 89 E	1.1			N 61 W	7.7			N 58 W	7.8

Altitude (meters) m. s. l.	Dallas, Tex. (154 meters) Direction	Velocity	Due West, S. C. (217 meters) Direction	Velocity	Ellendale, N. Dak. (444 meters) Direction	Velocity	Havre, Mont. (762 meters) Direction	Velocity	Jacksonville, Fla. (14 meters) Direction	Velocity	Key West, Fla. (11 meters) Direction	Velocity
	°		°		°		°		°		°	
Surface	S 5 E	1.0	S 45 E	0.2	N 47 W	0.7	S 88 W	0.6	S 73 W	0.7	S 65 E	2.3
500	S 32 W	7.6	N 62 W	2.1	N 81 W	0.7			S 74 W	4.9	S 61 E	5.8
1,000	S 38 W	7.0	N 82 W	3.1	S 39 W	1.9	N 86 W	2.3	S 71 W	4.1	S 57 E	6.0
1,500	S 32 W	5.0	N 87 W	3.0	S 65 W	3.3	N 69 W	4.6	S 76 W	2.8	S 60 E	5.6
2,000	S 12 W	3.3	S 80 W	2.8	N 87 W	5.4	N 72 W	5.0	S 80 W	1.9	S 65 E	4.7
2,500	S 9 E	2.0	S 77 W	2.6	N 78 W	7.5	N 83 W	6.3	S 87 W	1.3	S 68 E	4.7
3,000	S 46 E	1.2	N 89 W	3.0	N 74 W	9.5	N 88 W	8.0	S 84 W	1.8	S 72 E	3.9
4,000	S 83 E	1.6	S 83 W	2.8	N 77 W	9.6	N 84 W	11.4	S 52 W	2.1	S 48 E	1.8
5,000	N 62 E	1.0	S 85 W	3.1	N 68 W	12.2	S 85 W	16.1	S 70 W	1.4	N 45 E	2.8

Altitude (meters) m. s. l.	Los Angeles, Calif. (127 meters) Direction	Velocity	Medford, Oreg. (410 meters) Direction	Velocity	Memphis, Tenn. (145 meters) Direction	Velocity	New Orleans, La. (25 meters) Direction	Velocity	Oakland, Calif. (8 meters) Direction	Velocity	Oklahoma City, Okla. (392 meters) Direction	Velocity
	°		°		°		°		°		°	
Surface	N 31 E	0.3	S 48 W	0.4	S 12 E	0.8	S 73 W	0.2	N 37 W	1.1	S 5 E	1.7
500	S 85 E	1.6	W	0.9	S 28 W	3.3	S 42 W	3.1	S 84 W	2.7	S 11 W	4.5
1,000	N 12 E	0.7	N 62 W	1.2	S 46 W	2.6	S 27 W	3.1	N 65 W	3.7	S 39 W	7.8
1,500	N 46 W	2.0	N 72 E	0.8	S 55 W	2.0	S 1 W	2.9	S 86 W	2.3	S 49 W	6.4
2,000	N 55 W	1.4	S 82 E	1.3	S 33 W	2.0	S 12 E	2.1	S 46 W	2.3	S 54 W	3.6
2,500	S 51 E	0.9	S 34 W	3.5	S 24 E	3.1	S 6 W	1.9	S 30 W	2.2	S 52 W	2.5
3,000	S 71 E	2.1	S 34 W	5.6	S 24 W	3.5	S 9 E	2.0	S 16 W	2.1	S 76 W	1.1
4,000			S 55 W	7.4			S 77 W	0.6			N 32 W	1.6
5,000							N 29 E	1.1			N 12 W	0.9

Altitude (meters) m. s. l.	Omaha, Nebr. (299 meters) Direction	Velocity	Phoenix, Ariz. (356 meters) Direction	Velocity	Salt Lake City, Utah (1,294 meters) Direction	Velocity	Sault Ste. Marie, Mich. (198 meters) Direction	Velocity	Seattle, Wash. (14 meters) Direction	Velocity	Washington, D. C. (10 meters) Direction	Velocity
	°		°		°		°		°		°	
Surface	S 34 E	1.2	S 76 E	1.0	S 22 E	3.6	S 55 E	0.4	S 63 E	0.6	N 57 W	0.4
500	S 8 W	4.1	S 74 E	1.0			S 77 W	2.5	N 20 E	2.5	N 66 W	5.0
1,000	S 44 W	6.7	S 83 E	0.2			N 86 W	6.1	N 15 E	2.6	N 48 W	6.1
1,500	S 60 W	5.6	N 73 W	0.8	S 25 E	3.3	N 83 W	6.7	N 3 W	1.8	N 57 W	5.9
2,000	S 83 W	4.5	N 18 W	1.5	S 13 E	2.3	N 78 W	7.5	N 35 W	1.0	N 61 W	6.5
2,500	N 87 W	4.2	N 5 W	1.6	S 49 W	9.3	N 77 W	8.0	N 63 W	2.0	N 70 W	7.0
3,000	N 85 W	3.4	N 14 E	1.4	N 81 W	2.1	N 73 W	9.7	N 69 W	3.3	N 76 W	7.0
4,000	N 62 W	2.6	N 57 E	3.3	N 84 W	5.7	N 56 W	11.9			N 72 W	7.9
5,000	N 34 W	4.5	N 71 E	7.1	N 86 W	8.0	N 58 W	12.4				

TABLE 3.—*Observations by means of airplanes, kites, captive and limited heights sounding balloons during July, 1931*

	Dallas, Tex.[1]	Due West, S. C.	Ellendale, N. Dak.	Chicago, Ill.[1]	Cleveland, Ohio[1]
Mean altitudes (meters), m. s. l., reached during month	5,460	3,186	3,561	4,917	5,841
Maximum altitude (meters), m. s. l., reached	5,977	[2] 4,794	5,626	5,539	6,355
Number of flights made	31	26	31	31	31
Number of days on which flights were made	31	26	29	31	31

[1] Airplanes. [2] Limited-height sounding balloon observation.

WEATHER IN THE UNITED STATES

THE WEATHER ELEMENTS

[Climatological Division, Oliver L. Fassig in Charge]

By H. C. HUNTER

GENERAL SUMMARY

In practically all sections July was hotter than normal. The heat was comparatively steady in the majority of States, though several north-central stations set new high-temperature marks during the closing week. As a whole, the month was the hottest July ever recorded in most of the far Southwest and in portions of the Atlantic States; but the central area, while showing a large excess, failed to equal its earlier record.

The rainfall was irregular as to distribution, even within comparatively small areas. Usually there was more than normal from the Carolinas northward and northeastward, and along the Canadian boundary from Minnesota to Montana. Near the central and west Gulf coast there were some districts where marked shortages occurred, but amounts above normal were the rule, and several areas received quantities twice or thrice as great as normal. Deficient precipitation was the prevailing condition in the heart of the country and west of the Rocky Mountains. Most reports indicate numerous thunderstorms, abundant sunshine, and low relative humidity.

TEMPERATURE

The opening week of July was mainly hotter than normal, especially in the Lake region and the southeastern portion of the country, but about the 3d cool weather set in over the Missouri Valley, continuing until the 9th. After several days with temperature conditions showing no notable departures, high temperatures set in about the 14th to 16th over the Missouri and upper Mississippi Valleys and the Lake region, continuing without noteworthy break for the remainder of the month. The final decade was marked by considerable excess of temperature in the western and central thirds of the country and in the Northeast.

As a whole, July was at least as hot as normal in every State. In California and the Plateau region the month averaged about 5° to 7° hotter than normal, many stations in California and the western portions of Arizona and Nevada reporting it the hottest month of record. The departures of the mean temperature from the normal are shown on Chart I. As may be seen from that chart in the middle Rocky Mountain region and the middle and lower portions of the Missouri Valley, and thence eastward almost to the Atlantic coast, the month averaged usually 2° to 6° hotter than normal, and there was a like excess in the southern Appalachian region, where several stations noted that the mean temperature was higher than ever before in July.

In the lower Mississippi Valley the month was practically normal in its average temperature, and the same was true of Texas as a whole, but western and southwestern Texas averaged more than 1° cooler than normal.

Except in New England and Delaware, temperatures exceeding 100° were noted in every State. In Missouri, Minnesota, and Kansas, also all northern States from Nebraska and the Dakotas westward, and all Plateau and Pacific States there were readings of 110° or higher. The very highest temperature reported was 126° in southeastern California, while east of the Rocky Mountains 116° was noted at Redfield, S. Dak. The various States noted their highest temperatures usually during the first five days or between the 20th and the 29th.

The lowest temperature marks of the States were frequently in the 40's, but were higher in the Gulf and some of the least mountainous Atlantic States, while lower in the upper Lakes States, the northern Plains, the Rocky Mountain States, and the far West. The very lowest reported was 20° at three elevated stations in Colorado. The various low marks were noted chiefly between the 5th and the 12th.

PRECIPITATION

The inset on Chart V shows the departure of precipitation from normal.

The opening week of July brought much needed rains in many portions, especially Montana, North Dakota, the middle Plains, and from the central valleys eastward to the Carolina and Virginia coast. The succeeding week was mainly less rainy, but considerable parts of North Dakota, the upper Mississippi Valley, the southern Plains, and the Atlantic States had ample rainfall. Nearly all the Gulf coast districts received liberal amounts during the third week, as did the western half of the cotton region and the majority of States from Tennessee and North Carolina northward and northeastward. The final decade was marked by absence of substantial rains in most of the lower Missouri and upper Mississippi Valleys, and near Lakes Michigan and Superior; but, on the other hand, large parts of Arkansas, Mississippi, and Georgia, and of the upper Ohio Valley and northern New York and New England had abundant rains, and the last few days saw much rainfall over the Rocky Mountain and eastern Plateau regions, several portions of the Plains, and the west Gulf coast region.

The precipitation of July, as a whole, was comparatively well distributed and rather near to normal, for a summer month, this situation being more favorable than in almost any preceding summer month for several years. This was particularly true of the States which are situated east of the Plains, and wholly or largely south of the fortieth parallel of latitude, every one of these averaging at least 3 inches of rainfall and all save two having fully two-thirds of an inch at the stations reporting the least amounts. Mississippi received, on the average, almost 9 inches, and that State, with western Alabama and eastern Arkansas, had much greater rainfall than normal. Rainfall slightly above normal was the rule from the southern Appalachians and eastern South Carolina northward and northeastward, save that eastern New Jersey and southern New England fell short of normal. Usually there was more than normal from central Montana eastward over North Dakota to northwestern Minnesota, also from Montana southward to eastern Arizona, and in the central and southern portions of Texas.

There was usually considerably less rain than normal in the eastern portions of Florida and Georgia, the lower Ohio Valley, northern Ohio and adjacent parts of Michigan and Indiana, and southeastern Kansas and central Oklahoma. While there was considerable irregularity as to quantities received, there was mainly a decided shortage from northeastern Missouri northward to the vicinity of western Lake Superior and northwestward to beyond the Black Hills. The southwestern Plains and the eastern and central parts of New Mexico had moderate shortages, likewise southwestern Arizona, and practically all of Nevada, central and western Idaho, and the Pacific Northwest.

In Montana, as a whole, this was the first month to show more precipitation than normal since October, 1930; in Alabama and Mississippi, since November; and

in Oklahoma, Texas, and Arkansas, since March of the present year.

The largest monthly amount reported by any one station in the United States proper was 25.10 inches at Seven Hills, in Mobile County, Ala.

SUNSHINE AND RELATIVE HUMIDITY

The sunshine was of more than usual quantity during July in nearly all sections, even in most areas where the precipitation was heavy. The amount of sunshine was particularly large in the far Northwest and the upper Mississippi Valley; elsewhere it was usually equal to or moderately more than normal, but some portions of the central and eastern Lake region, the Ohio Valley and the Rio Grande Valley had less sunshine than normal.

The relative humidity was above normal in much of the Middle Atlantic and New England area, and often near the east Gulf coast and near the Rio Grande. Practically all other districts had less humidity than normal, the shortage being large in the middle and northern portions of the Plateau and Rocky Mountain regions, in most of the Plains and in the upper Mississippi Valley.

SEVERE LOCAL STORMS, JULY, 1931

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards [1]	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Fort Wayne, Ind	1	12:25 p. m.			$1,700	Thunderstorm	Power lines damaged; traffic delayed; large building of lumber company blown down; windows broken.	Official U. S. Weather Bureau.
Goff (near), Kans	1	12:30 p. m.	1,500		4,000	Tornado	Chief damage to large barn and small farm buildings; livestock killed or injured; path 1 mile long.	Do.
Indianapolis (near), Ind	1	1 p. m.				do	Occurred near airport, no damage reported	Do.
Darlington, Wis., and vicinity.	1	5:30 p. m.	880		25,000	do	Character of damage not reported	Do.
Port Arthur, Tex	1	6 p. m.		1	73,000	Thunderstorm	Lightning caused explosion and fire on oil barge	Do.
Bradford, Cumberland, Lancaster, Lebanon, and Dauphin Counties, Pa.	1	P. m.			300,000	Severe thunderstorm, wind and hail.	Many houses unroofed; heavy crop damage	Do.
Boone and Grundy Counties, Iowa.	1	P. m.			17,000	Wind and hail	Buildings and crops damaged	Do.
Tony (near), Wis	1	P. m.			8,000	Tornado	Large barn destroyed and another damaged	Do.
Audubon, Black Hawk, Bremer, Carroll, Cerro Gordo, Clay, Greene, Guthrie, Hamilton, Hancock, Harrison, Kossuth, and Marion Counties, Iowa.	1					Wind	Crops flattened; buildings damaged; a few poles blown down.	Do.
Beattie, Kans	1				500	Probably tornado.	Barns and fruit trees damaged	Do.
Indianapolis, Ind	1					Thunderstorm	2 houses struck by lightning; number of power and light poles damaged or blown down.	Do.
Marshall and Pocahontas Counties, Iowa.	1				55,000	Hail	Chief damage to crops	Do.
Maryland (central and western).	1					Wind	Trees blown down or broken off; buildings damaged.	Do.
Mounds, Ill	1					do	Plate glass windows broken; trees, roofs, and small buildings damaged.	Do.
Pratt County, Kans	1				50,000	do	Wheat badly twisted and blown down; minor damage to buildings.	Do.
Beckemeyer and Posey, Ill.	2	4 p. m.	4 mi.			do	Homes, outbuildings, and trees damaged; crops injured; path 10 miles long.	Do.
Buffalo, N. Y., and vicinity.	2				36,000	do	Buildings, hangar, and 5 planes damaged	Do.
Memphis, Tenn., and vicinity.	2				85,000	Thunderstorm	Schoolhouse and business building severely damaged.	Do.
Spearville (near), Kans	2				5,000	Hail	Character of damage not reported; area about 5 square miles.	Do.
Tama County, Iowa	2				3,000	Wind	Barns and other small buildings damaged	Do.
Grand Junction, Colo	3	5:04 – 5:13 p. m.	2 mi.		15,000	Hail	Damage chiefly to apples, melons, and tomatoes.	Do.
Sanders County, Mont	3				1,500	do	Roofs, auto tops, etc., damaged	Do.
Wilson, Hazen, and Slovaktown, Ark.	3				20,000	Wind	Character of damage not reported	Do.
Brown and Jackson Counties, Kans.	4	2:30-3 p.m.	3 mi.		20,000	Hail	Details not reported; path 10 miles long	Do.
Barber, Harper, Sumner, Kingman, and Sedgwick Counties, Kans.	4	2:30 – 3:30 p. m.				Wind	Chief damage at airport at Wichita; path 80 miles long.	Do.
Rogers, Ark., and vicinity	7				15,000	Hail	Character of damage not reported	Do.
Hamilton, Webster, and Dubuque Counties, Iowa.	8	2:30-3 p.m.			48,000	Hail and wind	Considerable damage to buildings and crops	Do.
Tyrone (near), Okla	8	5 p. m.	1-2 mi.		25,000	Hail	Damage mainly to crops; path 4 miles long	Do.
Cooke, Grayson, Collin, and Fannin Counties, Tex.	8	P. m.			3,800	Wind	Buildings unroofed; crops hurt	Do.
Lyon and Story Counties, Iowa.	8	P. m.			40,000	Hail	Considerable crop loss	Do.
Albuquerque, N. Mex. (10 miles east).	9	12:15 p. m.				Probably tornado.	No details reported	Do.
Alliance, Nebr	9	2-3 p. m.	4 mi.		60,000	Hail	Considerable damage to crops and some loss of livestock; path 5 miles long.	Do.
Jonesville, Va	9	3:30 p. m.	1.5 mi.		12,000	Hail and rain	Crops hurt; soil washed; buildings and bridges damaged.	Do.
Benton, Buchanan, Delaware, Dubuque, Franklin, Johnson, Linn, Mitchell, Polk, and Tama Counties, Iowa.	9				156,000	Hail	Crops total loss in some places; poultry killed	Do.
Pennsylvania (north central and northeastern).	9					Rain and electrical.	Cellars flooded; bridges washed away; heavy crop loss.	Do.
Waukesha County, Wis	10				5,000	do	Considerable damage, chiefly to crops	Do.
Belleville to Cuba, Kans	11	5 p. m.	2 mi.		8,000	Hail and wind	Trees broken; small buildings, poles, and wires blown down; path 4 miles.	Concordia Blade Empire (Kans.).

[1] "Mi." signifies miles instead of yards.

Severe local storms, July, 1931—Continued

Place	Date	Time	Width of path, yards [1]	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Rydal and Norway to Clifton and Greenleaf, Kans.	11	5 p. m.	15 mi.		$11,000	Wind	Chief damage to farm buildings and trees; path 40 miles long.	Official, U. S. Weather Bureau.
Cleburne to Fostoria, Kans.	11	6 p. m.	4 mi.		2,000	do.	Barns and trees damaged	Do.
Casselton to Mapleton, N. Dak.	11					Hail	Heavy crop damage	Do.
Hamilton, Harrison, Jasper, Mills, and Pottawattamie Counties, Iowa.	11					do.	Crops total loss in some localities	Do.
Gage and Jefferson Counties, Nebr.	12	3 p. m.	3-4 mi.		50,000	do.	Crops, windows and roofs damaged; poultry killed; path 10 miles.	Do.
Fremont, Marshall, Page, Tama, and Wayne Counties, Iowa.	12				81,700	Wind and hail	Crops beaten; buildings and cars damaged; livestock killed.	Do.
Six Mile, S. C.	13	9 p. m.			12,000	Thunderstorm	Lightning caused fire, which destroyed store and contents.	Do.
Sky Harbor Airport, Tenn.	13				5,000	Wind	Hangar and trees damaged	Do.
Philadelphia, Pa., and vicinity.	14	7:30 p. m.			1,000,000	Electrical and rain.	Parts of city severely damaged by water; damage by lightning in vicinity.	Do.
Alabama (southwestern)	14-15					Rain and wind	Bridges washed out; large areas inundated; traffic interrupted; telephone lines out of commission; crops damaged.	Do.
Moneta, Va.	14-15				2,000	2 severe hailstorms.	Character of damage not reported	Do.
Winnebago County, Ill.	15	12:45 a. m.	1,760		20,000	Wind	Buildings damaged; silos wrecked	Do.
Anne Arundel County, Md. (southwestern).	15	4 p. m.	880		1,000	Hail	Corn and tobacco hurt	Do.
Kent County, Md. (northwestern).	15	4 p. m.	2.5 mi.		25,000	do.	Crops, chiefly corn and tomatoes, damaged	Do.
Richmond, Va.	15	5 p. m.			5,000	Wind and electrical.	Buildings damaged; trees suffered; telephones out of commission.	Do.
Davidsonville, Md., and vicinity.	15				4,000	Wind	2 barns and silo wrecked; many trees prostrated	Do.
Jenison, Mich.	15					Probably tornado, wind and hail.	2 barns wrecked; grain crops leveled; many trees uprooted.	Do.
Rockpoint, Md. (north of)	15					Hail	Considerable tobacco ruined	Do.
Phillips, Sheridan, and Valley Counties, Mont.	15-16				199,300	do.	Extensive crop damage; much loss of livestock; buildings damaged.	Do.
Oakland, Md.	16	3-4 p. m.	200-880		300	Tornado	Minor damage to buildings; trees blown down	Do.
Richmond, Va.	16	5 p. m.			3,500	Wind and electric.	Telephone service disrupted; trees injured	Do.
Knoxville, Tenn.	16					Severe thunderstorm.	Some sections of city flooded; pavements torn up; traffic interrupted; some damage to buildings by lightning.	Do.
Morgan County, W. Va.	16					Hail	10,000 bushels of apples ruined	Do.
Pittsburgh, Pa.	16				25,000	Thunderstorm and wind.	Many small buildings unroofed; trees uprooted	Do.
Washington County, Md. (eastern).	16		1,760			Hail	Windows shattered; roofs pierced; grapevines, fruit and gardens injured; path 10 miles long.	Do.
Chambersburg, Pa.	17	2-2.30 p.m.		1	20,000	Electrical and rain	Property damaged chiefly by flooding	Do.
Sheboygan, Mich.	17	3.40-5 p.m.				Thunderstorm and wind.	Trees uprooted; small buildings overturned; other minor damage.	Do.
Jackson and O'Brien Counties, Iowa.	17				7,000	Hail and wind	Crops hurt; minor damage to buildings	Do.
Johnson City (near), Tenn.	17			2		Wind	Trees blown down at roadside fair; 8 persons injured.	Do.
Lisbon (near), Md.	17				3,500	Electrical	Barn and other outbuildings burned	Do.
Traverse City, Mich.	17				12,000	Wind squall	Blimp torn from mooring and damaged	Do.
Pana, Ill.	18			1		Electrical and wind	Barn burned; corn leveled over considerable area.	Do.
Wayne, Winneshiek and Linn Counties, Iowa.	19	P. m.			17,500	Wind, hail, and rain.	Crops and buildings damaged; sewers flooded	Do.
Chicago, Ill.	19					Thunderstorm	Streets and basements flooded; traffic delayed; trees uprooted.	Do.
Forestville and Sturgeon Bay, Wis., and vicinity.	19				50,000	Thunderstorm	Chief loss to cherry orchards	Do.
Simpsonville, S. C.	19				1,500	Electrical	Barn and contents destroyed	Do.
Brush, Hillrose, New Raymer, and Snyder, Colo.	20	5:30 - 8:30 p. m.	2-8 mi.	1	110,000	Hail and wind	Crops hurt; poultry and livestock killed; house wrecked, others damaged; light, telephone, and telegraph poles blown down.	Do.
Buffalo, N. Y.	20				75,000	Electrical	Yacht and soap factory set fire and 3 churches damaged.	Do.
Clint to Socorro, Tex.	20	2 p. m.	1.5 mi.			Hail	Crops injured 25 to 50 per cent	Do.
Winnsboro, S. C.	20	P. m.			3,000	Electrical	Building damaged	Do.
Marshall County, Ill. (northwestern).	21	3 p. m.	3 mi.		75,000	Hail	Heavy crop loss; path 4 miles	Do.
Quinlan, Tex.	21	3:45 p. m.	440		1,000	Tornado	Buildings damaged; path 1.5 miles long	Do.
Diamond Creek to Elmdale, Kans.	22	4-7 p. m.	1,760		6,000	Hail	Crops injured; path 5 miles long	Do.
Catlin, Ill., and vicinity	22	10 p. m.	4 mi.		190,000	do.	Heavy loss to crops; considerable damage to buildings and other property; path 8 miles long.	Do.
Connecticut (northcentral).	22					do.	Considerable damage to tobacco and other crops	Do.
Phillips and Roosevelt Counties, Mont.	22					Hail	Buildings and crops damaged; some loss of livestock.	Do.
Calhoun, Jersey, Macoupin, and Pike Counties, Ill.	22-23				423,500	Hail, wind, and electrical.	Crops severely damaged: schoolhouse and barn burned.	Do.
Montezuma and Port Byron districts, N. Y.	23	1:30 p. m.	3 mi.		32,000	Hail	Heavy damage to field crops and buildings	Do.
Ivy Depot, Va. (2 miles west of).	23	P. m.	1,320		5,000	do.	Fruit and corn injured	Do.
Frederick and Washington Counties, Md.	23					do.	Much injury to apple and peach crops	Do.
Snowflake to Taylor, Ariz.	23					Wind and hail	Crops almost total loss	Do.
Unionville, Md.	23				5,000	Electrical	Barn and contents burned	Do.
Stuttgart, Ark., and vicinity.	23-24				5,000	do.	Damage to power lines and equipment	Do.
Norfolk, Va.	24	12:30 p. m.				Wind squall	Many windows broken; trees uprooted	Do.
Alexandria, La. (Camp Beauregard.)	24	4:30-5 p.m.			15,000	Thundersquall	2 buildings wrecked, 1 moved from foundation; number of tents blown down; airplane demolished; many persons injured.	Do.
Frederick County, Md. (south-central).	24	7 p. m.	880-1,760		20,000	Hail and wind	Windows and roofs pierced; corn stripped; fruit injured; trees uprooted; path 10 miles long.	Do.
Shawnee, Okla. (8 miles northwest).	24	8 p. m.	50			Tornado	Damage confined to a few farms	Do.
Conway, Ark.	24				3,000	Wind	Character of damage not reported	Do.
Humboldt County, Nebr. (Leonard Creek Ranch.)	24				1,500	Violent dust whirl.	Lambing shed wrecked	Do.

[1] "Mi." signifies miles instead of yards.

Severe local storms, July, 1931—Continued

Place	Date	Time	Width of path, yards [1]	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Tuckerton, Pa.	24				$15,000	Electrical	No details reported	Official, U. S. Weather Bureau.
Maxwell (near), N. Mex.	25		3 mi.		3,000	Hail	Crops hurt; path 8 miles	Do.
Middle Hope and Marlboro, N. Y.	27	5:45 p. m.	1,320		2,000	Wind squall and rain.	Vineyards damaged	Do.
Moorhead, Minn., to Fargo, N. Dak.	27				12,000	Wind and hail	Crops and buildings damaged	Do.
Ganado to Fort Defiance, Ariz.	28	6 p. m.	4 mi.	3	275,000	Hail and rain	Severe loss to crops and stock; buildings and irrigation dam damaged.	Do.
Bernville, Pa.	29				10,000	Electrical	No details reported	Do.
Colchester and Winooski Valley, Vt.	29					Wind and rain	Trees and weak buildings blown down; crops hurt.	Do.
Lindrith, N. Mex.	30					Hail and rain	Corn and bean crops considerably damaged	Do.
Pomeroy (near), Wash.	30					Hail	Standing grain damaged 50 per cent.	Do.
Fillmore and Saline Counties, Nebr.	31	2-3 p. m.	2 mi.		10,000	do	Damage to crops estimated at 50 per cent in places; path 16 miles long.	Do.
Dallas County, Iowa	31	2:30 p. m.			4,100	Wind and hail	Buildings and crops damaged	Do.
Harmony, Nebr.	31	7 p. m.				Small tornado	A few outbuildings destroyed	Do.

[1] "Mi." signifies miles instead of yards.

RIVERS AND FLOODS

(River and Flood Division, Montrose W. Hayes in charge)

By RICHMOND T. ZOCH

The only overflows of consequence in the principal rivers of the United States during July, 1931, were those in the Pascagoula and Pearl River systems of Mississippi. These floods caused damage to the extent of $165,000, most of which was the result of 25,000 acres of prospective crops being inundated. The money value of property saved by warnings was estimated at $5,000.

The usual table of flood stages which occurred at Weather Bureau gaging stations appears herewith. No damage was reported at any of these places except that mentioned in the preceding paragraph.

Heavy local rains caused numerous overflows in creeks and small streams where it is impracticable to maintain warning service. Damages were reported (but the extent or amount was not given) at Bremen, Ohio, on July 2, at Cawker City, Kans., on July 6, in central Vermont on July 22, at Portsmouth, Ohio, on July 23, at Pocatello, Idaho, on July 29, and at Helena, Mont., and Cheyenne, Wyo., on July 30. On July 9 severe local rains caused floods in small streams in and around Scranton, Pa. The damage was estimated at $50,000. On July 14 a severe storm caused floods in the small streams in and around Philadelphia, Pa. The damage was estimated at $1,000,000.

The Mississippi River and nearly all of its tributaries remain at very low stages.

Table of flood stages in July, 1931

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ATLANTIC SLOPE DRAINAGE					
	Feet			*Feet*	
Susquehanna: Oneonta, N. Y.	12	11	11	12.0	11
Neuse: Smithfield, N. C.	14	5	5	14.2	5
Santee: Rimini, S. C.	12	13	13	12.2	13
EAST GULF OF MEXICO DRAINAGE					
Chickasawhay: Enterprise, Miss.	21	28	30	22.1	29
Pearl: Jackson, Miss.	20	28	31	22.3	31
MISSISSIPPI SYSTEM					
Red Basin.					
Sulphur: Ringo Crossing, Tex.	20	26	26	20.4	26
WEST GULF OF MEXICO DRAINAGE					
Rio Grande:					
Riogrande, Tex.	21	19	19	23.5	19
San Benito, Tex.	23	20	22	24.7	21
Brownsville, Tex.	18	21	22	18.5	22
GULF OF CALIFORNIA DRAINAGE					
Colorado: Parker, Ariz.	7	1	1	7.0	1
	------	8	14	7.2	9-11

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

By the Marine Division, W. F. McDONALD in charge

NORTH ATLANTIC OCEAN

By W. F. McDONALD

The average barometric pressures over the Atlantic and its adjacent coasts during July, 1931, did not depart greatly from the monthly normals except over Iceland, the British Isles, and Scandinavia, where the barometer averaged considerably below normal. From Halifax to the Spanish Peninsula there was a slight excess in average air pressure, and a slight deficiency from the Caribbean region to Bermuda and New England. (See Table 1.)

These conditions represent a displacement northeastward of the Atlantic centers of action during July, with some intensification of the usually inactive center of low pressure over the northeastern Atlantic, which is reflected in the fact that the British Isles experienced unusually cloudy and unsettled weather.[1] The pressure over southern Greenland (Julianehaab) continued above normal though not up to the extraordinary height shown by average pressure in the preceding month when the mean barometer was 30.07 inches.

[1] Monthly Supplement to the Daily Weather Report. British Meteorological Office July, 1931.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure (sea level) at selected stations for the North Atlantic Ocean and its shores, July, 1931*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland [1]	29.94	------	30.32	9th	29.53	1st.
Reykjavik, Iceland [1]	29.71	−0.12	30.10	7th	29.36	23d.
Aberdeen, Scotland [2]	29.68	−.24	[3] 30.01	1st	[3] 29.33	27th.
Valentia, Ireland [1]	29.83	−.18	[3] 30.20	21st	[3] 29.52	14th.
Lisbon, Portugal [1]	30.07	+.05	30.30	25th	29.94	22d.
Madeira [1]	30.11	−.02	------	------	29.95	22d.
Horta, Azores [1]	30.34	+.07	30.52	1st	30.08	10th.
Belle Isle, Newfoundland [1]	29.83	−.04	30.38	8th	29.38	5th.
Halifax, Nova Scotia [1]	29.96	+.01	30.26	10th	29.62	31st.
Nantucket [2]	29.93	−.05	30.13	13th	29.52	22d.
Hatteras [2]	29.96	−.05	30.16	14th	29.75	22d.
Bermuda [1]	30.09	−.04	30.28	25th	29.86	4th.
Turks Island [1]	30.05	−.02	30.18	12th	29.96	1st.
Key West [2]	29.97	−.06	30.10	20th	29.85	9th.
New Orleans [2]	29.96	−.04	30.15	30th	29.73	15th.

[1] All data based on a. m. observations only, with departure computed from best available normals related to time of observation.
[2] Corrected 24-hour means, based on more than one observation daily.
[3] Highest and lowest from one observation daily (a. m. only).

Reports in hand indicate that gales were experienced on only a few days in the month. The most disturbed conditions occurred over the main northern steamship routes east of longitude 45° W. during the latter half of the month, with three ships reporting winds of gale force in that area on the 16th and three on the 20th or 21st. These spells of mildly stormy conditions were the result of the development of an extensive low-pressure belt reaching from Labrador to the North Sea with a stable ridge of high pressure extending from Florida to Spain and crested well northward over the Azores.

The French steamship *Nevada* (captain, F. Bougouin; observer, LeFichoux) on the 14th encountered a small, sharp depression at the western end of the English Channel, in which the barometer dropped between noon and 7 p. m. from a reading of 29.9 to 29.1 inches, after which the pressure rose rapidly, the depression being accompanied by wind rising briefly to force 10, and shifting from east-northeast to west-northwest. This disturbance is clearly identified in the daily weather maps of the region, which show it to have traveled northeastward, retaining its central depth but increasing in area, though apparently not producing storm winds of any great extent.

A disturbance resembling in some of its characters a mild tropical cyclone originated in the western Gulf of Mexico on the 14th and caused winds of force 8 to 11 near the Louisiana coast as it progressed northeastward on the 14th and 15th. The tanker *W. C. Teagle* (captain, W. Doyle; observer, C. Dwyer) encountered this disturbance en route from Galveston through the Florida Straits, on the afternoon of the 14th, about latitude 28° N. and longitude 91° W. The barometer fell rather sharply about two-tenths of an inch, reaching the lowest point at 4:30 p. m., when the ship's weather journal states that "the wind was ESE., force 11, with driving rain squalls and the air full of spray. Kept the vessel head-on at reduced speed. At 6 p. m. the wind was SE., force 10, with barometer pumping between 29.72 and 29.78." Southeast gale and rain continued throughout most of the night of the 14th–15th, but the wind changed to south by 7 a. m. and diminished to force 6, with barometer returning to approximately the same height as at the beginning of the storm. The intensity of the disturbance may be judged, however, by the remark in the storm log that "the vessel was set north about 50 miles by wind and sea."

A wind of moderate gale force was experienced by the steamship *LaPlaya* in the Gulf of Honduras on the 23d, but this appears to have been the result of a local strengthening of the trade wind rather than a developing tropical disturbance.

Fogs were as prevalent as usual for July over the main steamer routes from North Atlantic ports eastward and northeastward, being most widespread between the 5th and 10th and again from the 22d to 28th, during which periods fog blanketed most of the Atlantic area north of latitude 40° and eastward to the vicinity of longitude 20° W., with a considerable extension southward along the American coast to the latitude of Hatteras from the 7th to 9th. There was another spell of extensive fogs over the mid-Atlantic between the 15th and 19th, but American waters were quite free between the 17th and 21st and again in the last five days of the month.

Three successful airplane crossings of the Atlantic were attempted during July. The first plane (Magyar and Endres) left the American coast on the 15th, landing near Budapest on the 16th. Two planes (Boardman and Polando in one, Herndon and Pangborn in the other) left simultaneously on the 28th, the first named making a nonstop flight from New York to Constantinople by which they claimed to have established a new mark for distance, in a traveling time of somewhat over 49 hours of flight. The second plane landed safely at Berlin.

It may be noted here that these flights were favored by stable barometric situations over the Atlantic, marked in each case by a well-developed ridge of high pressure extending completely across the ocean with long, almost straight, isobars parallel to the line of flight, creating steady tail winds over practically the entire stretch of ocean route. Charts VIII to XI reproduce the weather maps of the North Atlantic on July 15, 16, 28, and 29, for their interest in connection with these trans Atlantic flights.

OCEAN GALES AND STORMS, JULY, 1931

Vessel	Voyage		Position at time of lowest barometer		Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH ATLANTIC OCEAN			° ′	° ′				Inches					
Lochkatrine, Br. M. S.	Panama Canal.	Liverpool	27 56 N	58 16 W	July 1	4 p., 1	July 1	30.02	SSE	SSE, 8	SSE	SSE, 8	Steady.
Narragansett, Br. M. S.	Liverpool	Panama Canal.	48 48 N	18 33 W	July 3	6 p., 3	July 4	29.85	WSW	W, 6	WSW	WNW, 8	WSW-WNW.
Nevada, Fr. S. S.	Havre	do	49 00 N	2 00 W	July 14	7 p., 14	July 15	29.00	ESE	NNW, 10	NW	NNW, 10	
W. C. Teagle, Am. S. S.	Galveston	Cape Henry	27 44 N	90 42 W	do	4 p., 14	do	29.70	ESE	ESE, 11	SSE	ESE, 11	ESE-S.
Ambridge, Am. S. S.	Antwerp	New York	49 04 N	39 07 W	July 16	5 a., 16	July 17	29.78	WSW	SSW	SW	WSW, 9	SSW-WSW.
Gonzenheim, Ger. S. S.	Rotterdam	do	50 40 N	23 02 W	do	11 p., 16	do	29.89	W	W, 8	NW	W, 8	WSW-WNW.
Do	do	do	49 36 N	39 52 W	July 19	6 a., 20	July 20	29.81	S	SSW, 9	WSW	SSW, 9	SSW-WSW.
City of Alton, Am. S. S.	do	do	50 30 N	15 46 W	July 16	Mid., 16	July 17	29.96	W	W	SW	SW, 8	W-SW.
Do	do	do	48 45 N	38 25 W	July 20	2 a., 21	July 21	29.76	SW	SW	WNW	W, 8	SW-WNW.
Delfshaven, Du. S. S.	Antwerp	Baltimore	42 37 N	46 37 W	July 18	7 a., 19	July 19	30.08	S	S, 9	SW	SW, 9	S-SW.
Bird City, Am. S. S.	Copenhagen	Portland, Me.	56 55 N	30 00 W	July 21	Mid., 21	July 22	29.36	W	W, 5	WSW	W, 8	
La Playa, Pan. S. S.	Mobile	Puerto Cortez.	17 16 N	87 20 W	July 23	6 p., 23	July 24	29.78	ENE	NE, 7	ENE	ENE, 8	Steady.
Collamer, Am. S. S.	Bordeaux	New York	47 21 N	48 12 W	July 31	7 p., 31	Aug. 1	29.25	S	SSW, 9	WSW	SSW, 9	S-WSW.
NORTH PACIFIC OCEAN													
Golden Sun, Am. S. S.	San Francisco	Yokohama	44 00 N	151 30 W	July 2	6 p., 2	July 2	30.16	SSE	SSW, 8	SSW	SSW, 8	SSE-SSW.
Shintoku Maru, Jap. Bk.	Kobe	Honolulu	46 43 N	164 10 E	July 2	2 p., 3	July 4	29.79	SE	SE, 7	E	SE, 8	Steady.
Makiki, Am. S. S.	Hilo	San Francisco	36 00 N	127 00 W	do	5 a., 4	do	29.84	N	NNW, 6	NNW	NNW, 8	Do.
Emidio, Am. S. S.	San Pedro	Vancouver	39 40 N	124 24 W	July 3	2 p., 3	July 3	29.86	NNW	NNW, 7	NNW	NW, 8	
Challenger, Am. M. S.	Balboa	San Diego	16 20 N	99 57 W	do		do	29.55	E	E, 9	W	E, 9	E-W.
Ogura Maru, Jap. M. S.	Yokohama	Los Angeles	42 43 N	177 22 W	July 7	4 p., 8	July 8	29.42	ESE	NNE, 8	N	NE, 8	
Hanover, Am. S. S.	San Pedro	Kobe	32 35 N	140 25 E	July 9	11 a., 9	July 9	29.66	W	W, 8	W	W, 8	Steady.
San Diego Maru, Jap. M. S.	Yokohama	San Pedro	41 46 N	165 34 W	do	8 p., 9	July 10	29.33	E	E, 8	E	E, 8	Do.
Akagisan Maru, Jap. M. S.	do	San Francisco	42 47 N	157 50 E	do	Noon, 9	July 11	29.60	E	NNE, 2	ENE	ENE, 8	E-NNE.
Charcas, Am. S. S.	Buenaventura	San Pedro	15 00 N	96 00 W	July 10	2 p., 10	July 10	29.66	N	N, 7	SE	N, 8	
Atlantic, Am. S. S.	San Francisco	Panama	18 51 N	104 42 W	July 21	10 a., 21	July 21	29.84	SE	SSE, 5	SE	SE, 8	SE-SSE.
Effna, Am. S. S.	San Pedro	do	[1] 15 00 N	[1] 97 30 W	July 26	7 a., 26	July 26	29.63	NE	NE	SSE	NNE, 8	
Nora, Am. S. S.	do	Balboa	16 03 N	98 48 W	do	1 p., 26	do	29.67	ENE	ENE, 7	SE	E, 8	E-ESE.

[1] Position approximate.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

Atmospheric pressure.—While in June, 1931, the Aleutian LOW was better developed than normal for the month, in July, on the average, the depression had largely filled, with barometer higher than normal, except over the northwestern part of the Gulf of Alaska, where it was slightly below. Such shallow northern depressions as occurred extended from near Kodiak northward across Alaska into the Arctic Ocean, the average barometer at Point Barrow being 29.84 inches.

The North Pacific HIGH on the average covered a wide expanse of the ocean, with a greatest north-south extent from the central Bering Sea to the Hawaiian Islands, and a greatest northeast-southwest extent from eastern Alaska almost to the lower islands of Japan.

The following table gives barometric data for several island and coast stations in west longitudes, including Point Barrow on the Arctic Ocean:

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, North Pacific Ocean and adjacent waters, July, 1931, at selected stations*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Point Barrow [1]	29.84	−0.08	30.26	1st	29.44	30th.
Dutch Harbor [1]	30.02	+0.08	30.30	4th	29.64	26th.
St. Paul [1] [2]	30.00	+0.16	30.30	1st	29.66	24th.
Kodiak [1]	29.92	−0.02	30.20	4th [3]	29.42	17th.
Midway Island [1]	29.99	−0.12	30.10	11th [3]	29.80	7th. [3]
Honolulu [4]	30.01	−0.01	30.09	2d	[3] 29.90	31st.
Juneau [4]	30.05	0.00	30.43	5th	29.52	20th.
Tatoosh Island [4] [5]	30.04	−0.04	30.45	3d	29.69	20th.
San Francisco [4] [5]	29.84	−0.11	30.02	8th	29.67	24th.
San Diego [4] [5]	29.81	−0.11	29.93	9th	29.69	24th.

[1] P. m. observations in averages; a. m. and p. m. in extremes.
[2] For 30 days.
[3] And on other date or dates.
[4] A. m. and p. m. observations.
[5] Corrected to 24-hour mean.

Cyclones and gales.—The month of July passed without the appearance of any important cyclones on our charts over any part of the North Pacific Ocean. Aside from one or two Aleutian disturbances of moderate depth, the deepest depression occurring in middle and upper latitudes passed over northern Japan on the 26th. No high winds, however, so far as known, occurred in its vicinity. Scattered gales, in no instance exceeding force 8, were reported on a few days from the 2d to the 11th along the upper routes. A fresh gale was experienced south of Honshu on the 9th, while off the upper California coast and thence for approximately 500 miles southwestward, gales of similar force were encountered on the 2d and 3d. In the last instance the cause was a sharp pressure gradient on the eastern slope of the oceanic HIGH abutting upon a LOW over southern California.

Conditions were quiet in the Asiatic Tropics, with only slight depressions occurring. Off the Mexican west coast the weather was considerably disturbed, with indications that at least four tropical depressions or cyclones of sufficient energy to cause known gales of force 8 or 9 were developed. Observations were too limited, however, to give more than meager information as to storm formation and movement. The only disturbance among them mentioned by the Mexican weather maps was that of the 21st to 24th or 25th, with some violence of wind and precipitation indicated, as the cyclone progressed northwestward and entered the coast through the Gulf of California. The gale notations, some of which appear in the table of gales, as gathered from our vessel weather reports, show the following: On the 3d, south of Acapulco, occurred the highest wind thus far reported for the entire ocean for the mouth—an east gale of force 9, accompanied by a barometer depressed to 29.55 inches. On the 10th, at the western extremity of the Gulf of Tehuantepec, a fresh north gale occurred, with pressure down to 29.66 inches. On the 21st a fresh southeast gale was reported south of Manzanillo, with but slight barometric depression. On the 23d, in 16° 55′ N., 101° 35′ W., a moderate southeast gale was experienced, with lowest pressure 29.59 inches. At 9 p. m. of the 25th the American steamship *Ensley City* reported a barometer reading of 29.39, and an hour later a maximum wind force of 7 from the southwest in 13° 20′ N., 96° 08′ W. On the 26th, between Acapulco and Salina Cruz, fresh gales from east-southeast and north-northeast occurred, with lowest reported barometer, 29.63 inches. In a report from the American steamship *La Perla*, the observer, Mr. J. Walton, said: "July 21 and 22: Unsettled weather conditions along the Mexican coast. The Weather Bureau at Mexico advised that a hurricane was moving along the coast."

Winds at Honolulu.—The prevailing wind direction at Honolulu was east, with a maximum velocity of 24 miles from the northeast on the 21st.

Fog.—Over practically the entire region lying between the fortieth and fiftieth parallels fog showed a slight to heavy increase over that of June, the percentage of its occurrence rising gradually from the American coast westward toward the Kuril Islands. Over most of the western half of the ocean within these latitudes at least 40 to 60 per cent of the days had fog. Fog lessened rapidly south of the fortieth parallel, disappearing mainly at 35° N., except along the American coast. From Eureka southward to the middle coast of Lower California it occurred on 25 to 30 per cent of the days.

BUCKET OBSERVATIONS OF SEA-SURFACE TEMPERATURES

By GILES SLOCUM

STRAITS OF FLORIDA AND CARIBBEAN SEA

The temperatures herein published are the means of the average temperatures for the four quarters of the month, except that, in the case of the 5° subdivisions of the Caribbean Sea, the figures shown are the simple means of the observed temperatures with the entire month taken as a unit. Table 1 shows the lengths of the quarters for each length of month.

Table 2 shows the average temperature for the Caribbean Sea and the Straits of Florida for July of each year from 1919 to 1930, inclusive, and Table 3 summarizes the temperature for the month in the same areas, including the departures of the July, 1930, means from the 11-year means for July, 1920–1930, and the changes from the temperatures for the preceding month of June, 1930.

The chart shows the number of observations taken during the month of July, 1930, within each 1° square; the mean temperature of the Straits of Florida, and of each 5° [1] subdivision of the Caribbean Sea; the 11-year means (1920–1930) for these areas; and the local mean time corresponding to Greenwich mean noon, at which time the mariners are instructed to make the temperature readings.

[1] In three cases, as indicated on the chart, the observations from small, little traveled, and unimportant areas at the outer limits of the Caribbean Sea have been treated as parts of contiguous 5° subdivisions.

There is usually a slight increase during July in the surface temperatures of the Straits of Florida and the Caribbean Sea. The average rise is greatest in the straits during the first part of the month, and in the Caribbean near its end. In both areas the rise is least in the middle half of July, at which time the average temperatures show practically no change from one quarter-month to the next. Both areas are warmest later in the summer, the peak monthly and quarter-monthly averages occurring in August or in September.

The northwestern portion of the Caribbean Sea is warmer in July than the southern and eastern parts, and the coolest water is that off the coast of Venezuela. There is thus, during this month, a roughly progressive increase of temperature in the Caribbean from east to west and from south to north.

The northwestern waters of the Caribbean, in addition to being the warmest, also show the greatest June to July rise in temperature of any portion of the sea, while the southern salient of the Caribbean, bounded on the north by the line extending from Gallinas Point, Colombia, to Cape Gracias a Dios, Nicaragua, and on the south by the continents, cools slightly from June to July. The rest of the sea shows little or no clearly defined temperature range between the two months.

TABLE 1.—*Lengths of "quarter-months" used in computing mean sea-surface temperatures*

Length of month	Days of month included in quarter: I	II	III	IV
28 days	1-7	8-14	15-21	22-28
29 days	1-7	8-14	15-21	22-29
30 days	1-7	8-15	16-22	23-30
31 days	1-7	8-15	16-23	24-31

In July, 1930, the Caribbean Sea had a temperature near to or somewhat below the seasonal average from the seventieth meridian eastward, and was warmer than average over the rest of the area. The general average temperature, inclusive of the entire Caribbean Sea, was above the 11-year mean. These above-normal temperatures in the Caribbean had now persisted since March, 1930, or for five consecutive months.

The temperature of the Straits of Florida was close to the average except during the first quarter of July, when the region was cooler than is usual so late in the season.

TABLE 2.—*Mean sea-surface temperatures in the Caribbean Sea and the Straits of Florida for July, 1919–1930*

Year	Caribbean Sea: Number of observations	Caribbean Sea: Mean	Straits of Florida: Number of observations	Straits of Florida: Mean
		°F.		°F.
1919 [1]	88	81.4	18	82.4
1920	238	81.1	37	82.4
1921	277	81.2	68	82.6
1922	191	81.0	63	82.9
1923	358	81.2	89	82.8
1924	334	81.8	100	84.2
1925	552	81.5	121	83.2
1926	536	82.5	155	84.0
1927	654	82.2	226	83.9
1928	682	81.9	183	84.0
1929	723	81.6	202	82.1
1930	[2] 702	82.0	[3] 170	83.0
Mean (1920-1930)		81.6		83.1

[1] Not used in computations because of insufficient data available.
[2] Includes 7 intake readings.
[3] Includes 2 intake readings.

TABLE 3.—*Mean sea-surface temperatures (°F.), and number of observations, July, 1930*

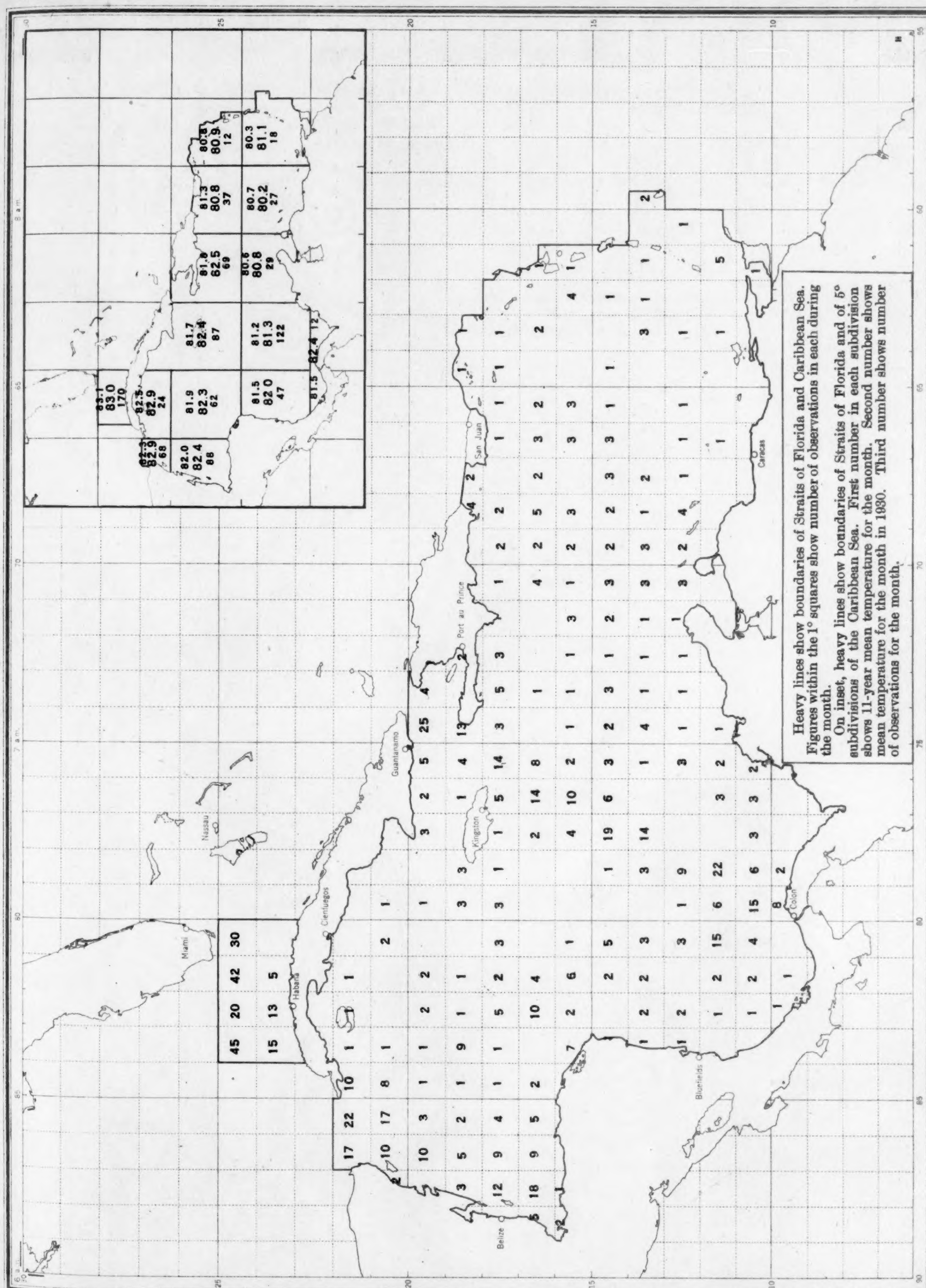
Quarter	Period	Caribbean Sea: Number of observations	Caribbean Sea: Mean	Caribbean Sea: Departure from 11-year mean (1920-1930)	Caribbean Sea: Change from preceding month	Straits of Florida: Number of observations	Straits of Florida: Mean	Straits of Florida: Departure from 11-year mean (1920-1930)	Straits of Florida: Change from preceding month
			°F.	°F.	°F.		°F.	°F.	°F.
I	July 1-7	161	81.8			37	82.3		
II	July 8-15	193	81.9			44	83.0		
III	July 16-23	170	82.2			50	83.2		
IV	July 24-31	178	82.0			39	83.3		
Month		[1] 702	82.0	+0.4	+0.5	[1] 170	83.0	−0.1	+2.6

[1] See notes 2 and 3, Table 2.

Distribution of Greenwich Mean Noon Bucket Observations of Sea-Surface Temperatures, July, 1930
(Plotted by Giles Slocum)

Distribution of Greenwich Mean Noon Bucket Observations of Sea-Surface Temperatures, July, 1930

(Plotted by Giles Slocum)



Heavy lines show boundaries of Straits of Florida and Caribbean Sea. Figures within the 1° squares show number of observations in each during the month.

On inset, heavy lines show boundaries of Straits of Florida and of 5° subdivisions of the Caribbean Sea. First number in each subdivision shows 11-year mean temperature for the month. Second number shows mean temperature for the month in 1930. Third number shows number of observations for the month.

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, July, 1931

[For description of tables and charts, see REVIEW, January, p. 50]

Section	Temperature								Precipitation					
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	81.8	+1.6	2 stations	104	[1] 2	Riverton	58	11	5.74	+0.37	Seven Hills	25.10	Tallassee	1.16
Arizona	83.7	+2.5	Quartzsite	119	2	Bright Angel[2]	38	5	2.28	-0.17	San Vicente	7.54	Marinette	0.00
Arkansas	81.0	+0.8	2 stations	106	2	Dutton	48	6	6.00	+2.25	White Cliffs	13.00	Morrilton	2.13
California	77.2	+4.2	Greenland Ranch	126	[1] 19	Madeline	30	[1] 1	0.04	-0.05	Lake Sabrina	1.48	182 stations	0.00
Colorado	69.7	+2.7	Las Animas	109	22	3 stations	20	[1] 7	1.42	-0.91	North Lake	4.51	Nast	0.08
Florida	82.8	+1.5	Monticello	106	3	Plant City	60	2	5.88	-1.27	Lake City	12.26	Fernandina	1.29
Georgia	83.1	+3.2	2 stations	108	[1] 2	Clayton	58	23	4.75	-1.00	Albany	10.57	Double Branches	1.77
Idaho	71.0	+2.4	Orofino	116	20	3 stations	25	[1] 1	0.30	-0.27	Blackfoot	1.42	7 stations	0.00
Illinois	79.1	+3.0	Sparta	108	1	Mount Carroll	46	[1] 8	2.92	-0.34	Hoopeston	9.39	Anna	0.42
Indiana	78.4	+3.1	Edwardsport	108	2	Marengo	43	11	3.08	-0.30	Butlerville	8.99	Monticello (near)	0.63
Iowa	77.2	+3.5	Lenox	109	28	Fayette	42	10	2.72	-1.11	Columbus Junction	7.87	Lansing	0.56
Kansas	80.4	+2.1	Russell	113	22	3 stations	43	[1] 5	2.32	-1.03	La Cygne	9.16	Richfield	T.
Kentucky	79.9	+3.1	Greensburg	104	31	2 stations	51	12	3.85	-0.29	Oneonta	9.51	Marion	0.45
Louisiana	82.9	+1.2	Dodson	105	[1] 2	Robeline	62	[1] 9	6.22	+0.10	Pearl River	14.56	Logansport	0.68
Maryland-Delaware	77.6	+2.4	Cumberland, Md	103	1	Sines, Md	44	26	4.53	+0.32	Keedysville, Md	8.48	Pocomoke City, Md	1.95
Michigan	72.5	+3.8	Hastings	105	1	Sidnaw	32	10	1.77	-1.10	Ishpeming	5.93	Scottville	0.25
Minnesota	72.3	+3.2	Beardsley	112	15	Big Falls	36	9	2.31	-1.00	Gonvick	5.55	Farmington	0.57
Mississippi	81.3	+0.3	Austin	105	1	2 stations	59	[1] 11	8.91	+3.89	Hickory	17.65	2 stations	4.01
Missouri	80.3	+3.0	Clinton	110	29	Dean	49	6	3.23	-0.77	Lockwood	8.66	Birchtree	0.43
Montana	68.5	+2.1	2 stations	110	[1] 21	Conways Ranch	24	1	1.67	+0.16	Valier	5.28	Ballantine	0.23
Nebraska	77.5	+2.8	Minden	111	22	Gordon	37	7	1.92	-1.42	Fairbury	5.30	Lyman	0.00
Nevada	78.2	+4.8	Logandale	119	25	2 stations	33	[1] 5	0.14	-0.21	Sharp	1.23	8 stations	0.00
New England	71.1	+2.1	2 stations	99	28	Somerset, Vt	41	26	4.24	+0.50	Cavendish, Vt	11.30	Lewiston, Me	1.51
New Jersey	76.6	+3.0	Runyon	102	1	Runyon	50	27	4.24	-0.29	Lambertville	7.55	Cape May	0.80
New Mexico	72.4	+0.7	Orogrande	108	28	2 stations	28	[1] 5	2.56	-0.21	Dunagans Ranch	10.12	Pasamonte	0.27
New York	72.6	+3.1	Geneva	104	2	Indian Lake	41	6	5.39	+1.46	Conklinville	12.47	Bardonia	1.80
North Carolina	79.3	+2.4	Fayetteville	106	2	2 stations	46	[1] 6	6.07	+0.23	Raleigh	12.36	Asheville	2.09
North Dakota	70.6	+2.2	3 stations	111	[1] 25	Linton	37	5	3.03	+0.61	Petersburg	5.36	Power	0.18
Ohio	77.2	+3.9	Circleville	105	16	Millport	44	12	3.77	-0.07	Circleville	7.73	Catawba Island	0.52
Oklahoma	82.9	+1.4	2 stations	109	4	Boise City	44	5	2.90	+0.29	Wichita National Forest.	9.59	Kenton	0.31
Oregon	68.7	+2.4	Umatilla	115	20	Seneca	21	1	0.01	-0.39	Seaside	0.33	87 stations	0.00
Pennsylvania	75.2	+3.2	2 stations	105	[1] 1	Ridgway	39	11	5.28	+0.99	Center Hall	13.28	New Castle	1.81
South Carolina	82.2	+2.4	Garnett	107	7	Caesars Head	58	11	5.35	-0.51	Chappells	9.20	Ellenton	2.08
South Dakota	77.0	+4.7	Redfield	116	15	Pollock	39	5	1.46	-1.31	Ludlow	3.89	Onida	0.08
Tennessee	80.2	+2.8	Etowah	105	3	Crossville	50	[1] 11	4.82	+0.44	Elkmont	14.70	Ashwood	1.24
Texas	83.0	0.0	Henrietta	108	[1] 2	Dalhart	50	5	3.08	+0.48	Corpus Christi	11.92	Brownwood	0.23
Utah	75.4	+3.9	2 stations	112	[1] 24	2 stations	28	[1] 5	0.79	-0.13	Cedar City	3.20	Wendover	T.
Virginia	78.2	+3.0	Lincoln	104	1	Burkes Garden	45	11	5.35	+0.84	Wallaceton	11.37	Bedford	1.73
Washington	67.6	+1.1	2 stations	112	20	Wilbur	30	1	0.16	-0.46	Big Four	1.49	31 stations	0.00
West Virginia	76.8	+4.0	Charleston	108	3	Bayard	42	12	4.78	+0.12	Charleston	10.74	St. Marys	0.93
Wisconsin	73.4	+4.0	2 stations	106	[1] 16	Coddington	35	24	2.00	-1.59	Sheboygan	5.04	Downing	T.
Wyoming	68.6	+2.9	Colony	111	25	Hunters Station	21	7	1.32	-0.09	Pathfinder	5.37	Deaver	0.10
Alaska [June]	51.7	-1.2	Anchorage	92	26	White Mountain	20	1	1.40	-0.15	Kodiak	7.70	2 stations	T.
Hawaii	74.8	+0.5	3 stations	92	[1] 4	Kanalohuluhulu	48	7	7.20	+1.09	Puohakamoa (No. 2)	30.40	.....do	0.00
Porto Rico	79.7	+0.9	San German	98	26	Guineo Reservoir	56	19	7.39	+0.64	San Lorenzo	14.68	Ponce	1.87

[1] Other dates also.

[2] Ranger station.

TABLE 1.—*Climatological data for Weather Bureau stations, July, 1931*

District and station	Elevation of instruments			Pressure			Temperature of the air									Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation			Wind					Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range				Total	Departure from normal	Days with 0.01 or more	Total movement	Prevailing direction	Maximum velocity: Miles per hour	Maximum velocity: Direction	Maximum velocity: Date						
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							70.9	+2.9										82	3.96	+0.5										5.9		
Eastport	76	67	85	29.84	29.92	-0.01	61.0	+0.6	83	29	69	45	2	53	29	58	56	88	4.82	+1.7	14	5,078	s.	24	s.	6	2	10	19	7.6	0.0	0.0
Greenville, Me	1,070	6	----	28.76	29.91	----	67.7	----	88	20	77	47	18	58	30	62	----	85	7.20	----	19	3,661	se.	20	nw.	31	5	15	11	----	0.0	0.0
Portland, Me	103	82	117	29.79	29.91	-.04	69.6	+1.5	95	29	77	56	18	62	27	63	60	78	2.72	-0.5	16	4,990	s.	24	sw.	20	14	10	7	4.7	0.0	0.0
Concord	289	70	79	29.60	29.90	-.06	71.6	+3.1	95	28	82	51	13	62	36	----	----	----	4.02	+0.5	14	3,127	se.	17	nw.	31	7	12	12	6.1	0.0	0.0
Burlington	403	11	48	29.46	29.88	-.06	72.2	+1.9	96	1	81	54	18	63	30	----	----	----	6.91	+3.4	16	5,140	s.	35	s.	6	3	13	15	6.8	0.0	0.0
Northfield	876	12	60	----	29.90	-.04	69.0	+3.1	94	1	80	49	13	57	36	----	----	82	5.10	+1.5	14	3,805	s.	25	sw.	29	2	24	5	6.0	0.0	0.0
Boston	125	106	165	29.78	29.91	-.05	74.0	+2.3	97	28	81	60	4	67	25	66	63	72	2.43	-1.1	9	4,796	sw.	23	nw.	31	4	18	9	6.0	0.0	0.0
Nantucket	12	14	90	29.92	29.93	-.05	69.4	+1.6	89	28	75	54	1	64	21	66	65	90	5.88	+3.0	10	9,111	sw.	30	sw.	29	9	10	12	5.5	0.0	0.0
Block Island	26	11	46	29.89	29.92	-.05	70.0	+1.6	88	28	75	58	2	65	18	67	65	89	2.11	-1.0	14	8,351	s.	36	sw.	22	8	15	8	5.9	0.0	0.0
Providence	160	215	251	29.75	29.92	-.05	73.7	+0.3	94	28	82	59	2	66	25	68	65	79	3.03	-0.2	13	6,310	nw.	25	nw.	31	8	13	10	5.4	0.0	0.0
Hartford	159	122	----	29.75	29.92	-.05	75.0	+3.4	96	28	84	58	26	66	26	----	----	----	2.51	-1.9	10	----	sw.	----	----	----	6	16	9	6.1	0.0	0.0
New Haven	106	74	153	29.81	29.92	-.05	74.6	+2.8	95	28	82	61	26	67	26	68	65	77	3.99	-0.3	13	4,802	s.	31	nw.	24	10	13	8	5.5	0.0	0.0
Middle Atlantic States							77.8	+2.9										76	4.91	+0.6										5.4		
Albany	97	107	115	29.80	29.90	-.06	76.0	+3.4	97	28	85	59	26	67	28	67	64	71	5.76	+2.3	15	4,181	s.	23	s.	20	17	9	5	4.1	0.0	0.0
Binghamton	871	10	84	29.01	29.92	-.05	74.0	+4.0	98	1	84	53	13	64	32	----	----	----	5.71	+2.0	15	2,949	w.	22	n.	29	4	12	15	6.8	0.0	0.0
New York	314	414	454	29.58	29.91	-.07	76.5	+2.7	94	28	83	63	3	70	19	68	65	74	4.55	+0.3	14	7,333	sw.	48	nw.	29	4	16	11	6.5	0.0	0.0
Bellefonte	1,050	5	36	28.84	29.93	----	73.1	----	99	1	85	48	12	61	36	67	65	79	4.53	----	13	----	sw.	----	----	----	8	13	10	6.0	0.0	0.0
Harrisburg	374	94	104	29.54	29.93	-.05	77.9	+3.1	100	1	87	60	12	69	26	69	65	70	3.89	+0.1	14	3,519	w.	24	nw.	23	9	15	7	4.8	0.0	0.0
Philadelphia	114	123	367	29.81	29.92	-.06	79.8	+3.6	98	1	88	67	4	72	24	70	66	68	7.99	+3.8	11	6,984	sw.	53	n.	14	9	13	9	5.6	0.0	0.0
Reading	325	81	98	29.58	29.92	----	78.0	+2.5	99	1	88	61	12	68	28	69	65	70	4.55	+0.3	13	3,207	nw.	19	nw.	29	9	13	9	5.1	0.0	0.0
Scranton	805	111	119	29.09	29.93	-.05	75.0	+3.3	97	1	85	54	13	65	32	68	64	72	8.74	+4.7	13	3,368	sw.	21	nw.	29	5	19	7	6.0	0.0	0.0
Atlantic City	52	37	172	29.86	29.91	-.07	76.7	+4.6	93	15	83	65	3	71	20	71	68	81	1.67	-2.3	5	8,874	s.	37	se.	6	7	20	4	5.1	0.0	0.0
Cape May	17	13	49	----	----	----	76.9	+3.5	93	15	84	63	26	70	21	71	69	84	0.80	-3.0	9	----	se.	----	----	----	5	22	4	----	0.0	0.0
Sandy Hook	22	10	55	29.88	29.90	----	76.6	----	94	28	83	64	3	70	22	71	68	82	2.44	-2.7	14	6,953	sw.	36	w.	29	6	16	9	5.3	0.0	0.0
Trenton	190	159	183	29.72	29.92	----	77.5	+2.1	96	28	86	63	3	68	27	69	66	72	5.47	+1.5	9	5,055	sw.	31	nw.	14	10	10	11	5.7	0.0	0.0
Baltimore	123	100	215	29.79	29.91	-.07	81.0	+3.8	101	1	90	67	11	72	25	71	67	68	6.04	+1.4	14	5,280	sw.	50	ne.	1	10	14	7	4.9	0.0	0.0
Washington	112	62	85	29.81	29.92	-.08	79.6	+2.8	97	29	89	64	26	70	27	71	68	75	4.23	-0.5	16	2,844	sw.	32	e.	1	10	13	8	4.8	0.0	0.0
Cape Henry	18	8	54	29.91	29.93	----	79.1	+1.6	98	30	86	65	27	72	25	73	72	82	6.47	+1.1	12	5,997	sw.	64	nw.	1	11	12	8	5.2	0.0	0.0
Lynchburg	681	153	188	29.22	29.94	-.07	80.2	+2.7	99	31	91	63	11	70	27	72	69	74	5.37	+1.2	17	2,960	w.	26	n.	10	13	15	3	4.5	0.0	0.0
Norfolk	91	170	205	29.85	29.94	-.06	80.6	+1.9	96	30	89	68	24	72	25	73	70	78	4.56	-1.2	11	6,528	s.	38	ne.	16	10	11	10	5.4	0.0	0.0
Richmond	144	11	52	29.80	29.94	-.07	80.4	+1.9	100	30	90	66	12	70	28	73	70	79	4.47	-0.3	15	3,706	sw.	28	e.	15	8	17	6	5.1	0.0	0.0
Wytheville	2,304	49	55	27.67	29.95	-.06	74.1	+1.5	94	2	85	51	11	63	32	68	66	81	5.68	+1.7	21	2,922	w.	17	ne.	9	6	18	7	5.7	0.0	0.0
South Atlantic States							81.8	+2.7										77	5.49	-0.3										5.3		
Asheville	2,253	89	104	27.71	29.97	-.05	76.6	+4.9	93	2	88	61	23	65	27	68	66	82	2.09	-2.2	15	2,953	nw.	26	se.	9	8	20	3	4.7	0.0	0.0
Charlotte	779	55	62	29.15	29.96	-.06	82.5	+4.1	101	2	93	67	15	72	28	72	70	75	8.62	+3.5	14	2,042	sw.	23	se.	15	7	19	5	5.3	0.0	0.0
Greensboro	886	6	56	29.03	29.97	----	79.8	----	98	2	90	63	11	69	27	72	70	80	5.22	----	12	3,632	sw.	38	nw.	7	6	18	7	5.7	0.0	0.0
Hatteras	11	5	50	29.94	29.96	-.06	78.6	+0.4	89	19	85	68	28	72	17	75	73	84	4.82	-0.7	11	6,610	sw.	46	nw.	18	11	14	6	4.9	0.0	0.0
Raleigh	376	103	146	29.56	29.95	-.05	81.4	+2.6	98	30	91	68	11	72	27	73	71	76	12.36	+7.0	10	3,958	sw.	28	nw.	18	6	18	7	5.8	0.0	0.0
Wilmington	78	81	91	----	29.98	-.03	81.8	+2.7	96	7	90	69	27	74	23	----	----	82	6.33	-0.8	14	3,966	sw.	21	ne.	17	8	19	4	----	0.0	0.0
Charleston	48	11	92	29.93	29.98	-.05	82.9	+1.5	101	2	90	70	11	76	27	77	75	79	6.88	0.0	15	5,772	sw.	34	n.	2	7	11	13	5.9	0.0	0.0
Columbia, S. C.	351	41	57	29.59	29.97	-.06	82.8	+1.9	101	2	93	67	26	72	31	73	70	74	5.55	+0.2	11	3,653	sw.	46	ne.	2	9	21	1	4.5	0.0	0.0
Due West	711	10	55	29.24	29.99	----	81.9	----	99	3	92	66	27	71	26	----	----	----	3.94	----	12	4,031	sw.	32	nw.	21	5	18	8	5.7	0.0	0.0
Greenville, S. C.	1,039	139	146	28.90	29.96	----	81.5	+4.6	99	3	92	65	11	71	27	72	69	73	4.38	-1.0	15	3,922	ne.	34	w.	21	8	19	4	5.0	0.0	0.0
Augusta	182	62	77	29.76	29.95	-.07	84.7	+3.4	103	3	96	69	12	74	28	75	71	71	3.34	-2.0	13	3,103	s.	25	nw.	19	8	21	2	4.9	0.0	0.0
Savannah	65	150	194	29.90	29.97	-.06	83.5	+2.0	101	3	93	70	14	74	26	75	73	77	3.81	-2.8	13	6,176	s.	35	s.	24	8	9	14	5.9	0.0	0.0
Jacksonville	43	209	245	29.95	30.00	-.03	83.8	+1.7	98	3	92	70	19	76	26	75	73	76	2.20	-4.5	13	6,375	sw.	34	sw.	19	8	18	5	5.3	0.0	0.0
Florida Peninsula							83.5	+1.6										78	4.36	-1.2										6.0		
Key West	22	10	64	29.95	29.97	-.06	83.6	+0.1	92	9	89	74	12	78	14	77	75	76	3.23	0.0	13	6,067	se.	25	se.	26	6	15	10	6.1	0.0	0.0
Miami	25	124	168	29.98	30.01	-.04	82.8	+1.8	91	7	88	73	3	78	16	76	74	75	2.63	-2.8	10	5,580	se.	31	se.	26	3	15	13	6.8	0.0	0.0
Tampa	35	86	197	29.96	30.00	-.04	84.0	+2.8	96	25	92	71	2	76	23	76	75	82	7.23	-0.7	15	5,742	se.	32	sw.	5	3	20	8	6.1	0.0	0.0
Titusville	44	5	----	29.96	30.01	----	84.0	----	98	7	94	70	2	74	25	----	----	----	5.38	----	10	----	se.	----	----	----	11	13	7	5.1	0.0	0.0
East Gulf States							82.0	+1.4										77	7.30	+1.5										6.0		
Atlanta	1,173	190	216	28.78	29.98	-.04	81.0	+2.9	96	3	90	68	24	72	23	71	68	73	5.34	+0.7	11	4,961	w.	26	sw.	23	5	16	10	6.2	0.0	0.0
Macon	370	78	87	29.59	29.97	-.05	83.2	+2.0	102	3	93	68	9	73	27	74	70	70	6.49	+1.8	11	3,216	sw.	23	nw.	10	6	15	10	5.9	0.0	0.0
Thomasville	273	49	103	29.70	29.98	-.05	83.0	+1.2	100	2	93	69	23	73	25	75	73	82	6.55	-0.2	15	3,988	sw.	30	sw.	3	2	18	11	6.3	0.0	0.0
Apalachicola	36	11	51	29.95	29.99	----	82.6	----	94	3	89	71	23	76	17	77	75	78	5.72	-2.0	13	4,753	w.	32	se.	12	11	13	7	4.9	0.0	0.0
Pensacola	56	149	185	29.92	29.98	-.03	80.6	-0.4	90	5	86	70	25	76	17	76	74	80	11.11	+4.3	14	7,338	w.	38	s.	10	4	16	11	6.1	0.0	0.0
Anniston	741	9	57	----	----	----	81.2	+3.3	97	18	92	65	11	70	31	----	----	----	5.10	----	10	2,126	w.	16	nw.	21	11	12	8	----	0.0	0.0
Birmingham	700	11	48	29.24	29.99	-.02	81.8	+1.6	101	9	92	67	24	71	29	72	70	78	3.96	-1.2	16	3,095	sw.	27	s.	12	7	13	11	5.9	0.0	0.0
Mobile	57	125	161	29.92	29.98	-.03	82.2	+0.8	96	31	90	70	22	74	24	75	74	83	17.99	+11.1	16	5,391	sw.	32	e.	10	5	15	11	6.4	0.0	0.0
Montgomery	223	100	112	29.74	29.98	-.04	82.9	+1.2	98	8	92	70	27	74	22	74	71	75	3.18	-1.7	8	3,685	w.	22	nw.	21	4	14	13	6.6	0.0	0.0
Corinth	469	6	----	----	----	----	81.7	----	101	12	92	61	11	71	35	----	----	----	4.01	----	16	----	s.	----	----	----	4	25	2	----	0.0	0.0
Meridian	375	87	95	29.58	29.97	-.05	80.6	+0.2	97	1	90	66	24	72	20	73	70	77	8.14	+3.2	16	3,277	sw.	28	nw.	21	5	12	14	6.5	0.0	0.0
Vicksburg	247	65	73	29.70	29.97	-.03	81.6	+0.3	96	11	90	68	23	73	26	74	72	79	4.08	-0.4	13	4,066	se.	31	ne.	23	8	11	12	5.3	0.0	0.0
New Orleans	53	76	84	29.91	29.96	-.04	84.2	+1.8	98	9	92	70	15	77	19	76	74	76	7.77	+1.4	12	3,952	sw.	28	se.	15	6	20	5	5.6	0.0	0.0
West Gulf States							83.2	+0.6										73	3.29	+0.2										4.0		
Shreveport	249	204	220	29.66	29.92	-.06	84.2	+1.0	101	2	94	70	9	74	26	74	70	71	1.66	-1.9	8	4,825	s.	30	n.	21	11	11	9	4.9	0.0	0.0
Bentonville	1,303	11	44	28.59	29.92	-.05	79.0	+0.5	98	4	90	55	6	68	36	----	----	----	4.77	----	9	2,612	s.	25	ne.	24	26	3	2	----	0.0	0.0
Fort Smith	457	79	94	29.44	29.90	-.07	83.3	+1.8	102	1	94	64	6	73	31	73	68	67	3.10	-0.3	9	3,864	e.	26	se.	8	10	14	7	5.0	0.0	0.0
Little Rock	357	136	153	29.57	29.94	-.05	81.7	+0.6	101	1	91	66	11	73	27	73	70	74	3.74	+0.2	17	4,500	sw.	34	ne.	24	6	9	16	6.3	0.0	0.0
Austin	605	136	148	29.29	29.92	----	84.0	0.0	100	11	93	68	15	74	27	74	70	70	2.74	+0.4	9	4,323	s.	39	nw.	15	14	8	9	4.6	0.0	0.0
Brownsville	57	53	100	29.53	29.90	----	83.8	+0.2	95	9	91	73	17	76	19	76	74	79	2.79	+0.8	9	5,626	se.	28	se.	22	11	17	3	4.6	0.0	0.0
Corpus Christi	20	11	78	29.90	29.92	-.05	83.4	+0.7	94	10	89	71	18	78	17	77	75	80	11.92	+10.4	10	6,278	se.	33	se.	18	10	14	7	5.2	0.0	0.0
Dallas	512	220	227	29.38	29.92	----	84.6	----	100	2	94	68	8	76	29	----	----	----	1.61	-1.2	4	6,475	s.	59	n.	8	13	13	5	3.9	0.0	0.0
Fort Worth	670	106	114	29.20	29.89	-.07	84.8	+1.2	102	8	95	67	8	75	35	72	67	63	0.44	-2.2	4	5,207	sw.	38	ne.	8	13	12	6	4.6	0.0	0.0
Galveston	54	106	114	29.90	29.96	-.02	84.2	+0.5	96	10	89	73	17	80	15	77	74	76	1.02	-2.7	8	6,634	s.	24	se.	29	15	11	5	3.9	0.0	0.0
Houston	138	202	314	29.79	29.93	----	84.2	+0.5	97	2	92	72	14	76	22	----	----	----	3.39	-0.6	10	6,143	s.	35	w.	15	14	14	3	4.3	0.0	0.0
Palestine	510	64	72	29.42	29.94	-.03	83.0	+0.8	102	8	93	67	13	73	34	74	71	74	5.39	+2.7	9	4,115	s.	26	ne.	8	12	13	6	4.4	0.0	0.0
Port Arthur	34	58	66	29.90	29.94	----	84.3	----	96	10	92	71	9	77	25	76	74	75	3.10	-3.8	14	4,724	s.	25	e.	28	10	14	7	4.7	0.0	0.0
San Antonio	693	242	301	29.20	29.90	-.05	82.6	-1.2	96	13	91	71	17	74	23	73	70	72	3.09	+0.9	9	6,491	s.	31	se.	11	15	11	5	4.4	0.0	0.0
Taylor	571	38	51	29.30	29.96	.00	83.6	+0.9	99	8	94	69	16	73	27	----	----	----	2.07	-0.2	7	4,558	s.	34	e.	2	19	8	4	3.8	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, July, 1931*—Continued

District and station	Elevation of instruments: Barometer above sea level	Thermometer above ground	Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Departure from normal	Days with 0.01 or more	Wind: Total movement	Prevailing direction	Maximum velocity: Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
Ohio Valley and Tennessee							79.4	+3.1										68	4.29	+0.5										4.8		
Chattanooga	762	190	215	29.16	29.95	-0.07	80.9	+2.5	96	17	90	67	11	71	26	72	68	71	4.08	-0.2	10	4,337	sw.	36	nw.	19	5	17	9	6.0	0.0	0.0
Knoxville	995	102	111	28.94	29.97	-.05	81.0	+3.9	98	2	92	66	12	70	28	71	68	72	7.94	+3.6	12	3,293	sw.	29	sw.	21	11	14	6	4.7	0.0	0.0
Memphis	399	76	97	29.53	29.94	-.06	80.6	-0.1	100	1	89	67	23	72	28	73	70	74	4.37	+1.2	15	4,315	sw.	34	n.	2	6	14	11	5.9	0.0	0.0
Nashville	546	168	191	29.40	29.97	-.04	81.6	+2.5	97	12	91	64	11	72	30	72	68	70	2.47	-1.4	10	4,080	w.	27	e.	8	6	16	9	5.3	0.0	0.0
Lexington	989	193	230	28.94	29.98	-.03	79.4	+3.5	96	17	89	63	11	70	24				8.50	+4.8	11	6,322	s.	40	w.	5	15	13	3	3.4	0.0	0.0
Louisville	525	188	234	29.39	29.96	-.04	81.2	+2.6	97	14	91	62	12	72	29	70	66	65	1.73	-2.0	10	5,091	sw.	43	nw.	19	16	11	4	4.2	0.0	0.0
Evansville	431	76	116	29.48	29.94	-.06	82.1	+3.4	99	2	92	64	11	72	30	71	65	61	0.73	-2.7	4	4,499	sw.	22	w.	22	17	9	5	4.0	0.0	0.0
Indianapolis	822	104	230	29.07	29.94	-.05	79.7	+4.0	98	2	89	60	11	70	25	67	61	58	2.95	-0.4	9	5,470	sw.	35	se.	18	17	11	3	3.6	0.0	0.0
Royal Center	736	11	55	29.17	29.94	------	76.4	------	98	16	88	51	11	65	30				2.62	-1.2	9	4,375	sw.	35	n.	21	17	10	4	4.0	0.0	0.0
Terre Haute	575	96	129	29.33	29.93	------	80.4	------	101	2	91	60	11	70	27	69	64	62	3.38	+0.2	6	4,403	sw.	24	n.	3	18	8	5	3.5	0.0	0.0
Cincinnati	627	11	51	29.29	29.95	-.05	79.2	+4.1	99	16	90	56	12	68	32	69	65	67	5.22	+1.9	11	3,231	sw.	30	sw.	22	18	10	3	3.5	0.0	0.0
Columbus	822	216	230	29.09	29.94	-.06	78.6	+3.7	98	16	89	61	11	68	26	68	63	64	4.66	+1.1	7	5,029	sw.	34	se.	31	8	19	4	4.6	0.0	0.0
Dayton	899	137	173	29.01	29.93	------	78.9	+3.5	98	16	90	57	12	68	31	68	63	63	6.74	+3.4	9	4,179	sw.	28	sw.	22	11	18	2	4.4	0.0	0.0
Elkins	1,947	59	67	28.00	29.97	-.04	73.0	+2.7	93	2	85	50	12	61	37	66	64	81	5.27	-0.1	13	2,388	nw.	28	nw.	20	9	14	8	5.0	0.0	0.0
Parkersburg	637	77	82	29.32	29.97	-.04	79.6	+4.2	99	1	90	57	12	69	30	69	65	68	2.62	-1.7	8	2,877	se.	23	w.	2	13	8	10	5.1	0.0	0.0
Pittsburgh	842	353	410	29.06	29.94	-.06	77.0	+2.4	97	2	87	57	12	67	29	68	64	69	5.36	+1.3	12	4,826	n.	45	n.	16	8	13	10	5.5	0.0	0.0
Lower Lake Region							75.4	+4.0										68	2.89	-0.4										5.1		
Buffalo	767	247	280	29.09	29.90	-.07	72.3	+2.5	91	2	78	57	10	66	23	66	63	74	3.24	+0.2	11	7,934	sw.	52	nw.	2	10	10	11	5.5	0.0	0.0
Canton	448	10	61	29.41	29.87	------	72.0	+1.5	98	1	82	54	25	62	28				4.91	+1.4	13	4,696	sw.	26	sw.	29	4	18	9	6.0	0.0	0.0
Ithaca	836	74	100	29.03	29.90	------	74.6	+4.1	102	2	85	54	26	64	34	67	63	71	2.73	-0.8	13	4,336	nw.	29	se.	5	6	15	10	6.3	0.0	0.0
Oswego	335	71	85	29.54	29.90	-.06	73.0	+2.6	93	2	80	59	25	66	25	67	63	73	2.49	-0.4	11	4,373	s.	21	n.	31	4	14	13	6.3	0.0	0.0
Rochester	523	86	102	29.36	29.92	-.05	74.8	+4.1	99	2	83	58	12	66	25	66	62	67	2.63	-0.3	11	4,314	sw.	28	w.	29	8	16	7	5.5	0.0	0.0
Syracuse	596	65	79	29.29	29.92	-.05	75.4	+4.6	100	2	84	60	12	66	26				3.81	+0.1	14	3,651	s.	21	sw.	29	6	15	10	5.9	0.0	0.0
Erie	714	130	166	29.17	29.92	-.05	75.0	+4.0	92	2	82	56	10	67	26	70	68	79	5.75	+2.7	14	6,454	sw.	36	nw.	10	15	8	8	4.2	0.0	0.0
Cleveland	762	267	337	29.12	29.92	-.07	76.3	+5.9	96	17	83	61	11	69	23	67	61	61	2.17	-1.3	10	6,473	n.	50	sw.	19	12	14	5	4.7	0.0	0.0
Sandusky	629	5	67	29.27	29.94	-.05	78.0	+4.6	99	17	88	58	11	68	30				1.03	-2.4	9	4,254	sw.	19	s.	5	9	16	6	4.9	0.0	0.0
Toledo	628	208	243	29.27	29.93	-.06	77.8	+4.6	99	17	87	61	24	68	26	67	61	60	1.24	-1.8	6	6,993	sw.	38	sw.	19	16	13	2	3.5	0.0	0.0
Fort Wayne	856	100	119	29.03	29.94	------	77.6	+4.1	99	17	88	55	11	67	27	67	62	62	2.56	-1.0	6	4,672	sw.	31	e.	1	15	12	4	3.8	0.0	0.0
Detroit	730	218	258	29.16	29.93	-.05	77.6	+5.5	100	17	87	60	10	68	27	67	62	64	1.81	-1.5	6	5,348	sw.	26	sw.	19	9	21	1	4.2	0.0	0.0
Upper Lake Region							72.0	+4.2										68	2.48	-0.6										4.4		
Alpena	609	13	92	29.26	29.92	-.05	70.2	+4.3	98	28	81	50	25	60	34	64	60	70	1.78	-1.0	10	6,498	nw.	40	nw.	16	11	13	7	4.5	0.0	0.0
Escanaba	612	54	60	29.25	29.90	-.07	69.6	+3.6	95	26	78	50	11	61	26	62	58	69	3.42	+0.1	11	5,731	s.	37	n.	19	12	13	6	4.3	0.0	0.0
Grand Haven	632	54	89	29.25	29.92	-.06	72.4	+3.7	92	16	81	51	12	64	29	65	61	66	2.63	0.0	7	6,050	sw.	30	nw.	17	15	9	7	4.3	0.0	0.0
Grand Rapids	707	70	244	29.18	29.92	-.06	75.8	+3.5	100	1	86	54	11	65	33	65	58	56	2.58	-0.3	5	6,577	sw.	33	sw.	5	14	9	8	4.8	0.0	0.0
Houghton	668	64	99	29.16	29.87	-.09	68.8	+3.3	95	1	78	50	10	60	34				1.52	-1.6	10	6,663	w.	30	e.	15	11	12	8	5.2	0.0	0.0
Lansing	878	6	88	29.00	29.92	------	73.8	+2.9	96	17	85	52	12	62	33	66	62	68	0.92	-2.2	7	4,301	sw.	18	w.	5	14	11	6	4.3	0.0	0.0
Ludington	637	60	66	29.24	29.92	------	70.9	+4.7	89	1	78	50	10	63	23	66	63	75	0.41	-2.6	6	5,854	s.	27	s.	5	20	7	4	2.8	0.0	0.0
Marquette	734	77	111	29.10	29.89	-.07	69.8	+4.9	100	1	79	51	11	61	29	62	57	68	4.65	+1.5	11	6,205	w.	37	sw.	27	9	13	9	5.4	0.0	0.0
Port Huron	638	70	120	29.23	29.92	-.06	73.9	+5.1	97	1	83	54	11	65	32	66	62	69	3.58	+0.8	11	5,693	s.	38	w.	17	12	11	8	4.7	0.0	0.0
Sault Sainte Marie	614	11	52	29.22	29.90	-.07	67.8	+4.0	97	1	77	47	10	58	32	62	58	73	2.33	-0.6	7	4,534	nw.	26	s.	19	15	12	4	4.2	0.0	0.0
Chicago	673	7	131	29.22	29.94	-.04	76.4	+3.9	99	1	84	60	6	69	24	67	63	67	2.68	-0.6	10	5,612	ne.	22	w.	17	17	10	4	3.5	0.0	0.0
Green Bay	617	109	141	29.25	29.90	-.07	75.0	+5.0	100	16	85	54	11	65	31	64	59	62	3.31	-0.2	10	6,188	sw.	35	w.	17	10	13	8	5.1	0.0	0.0
Milwaukee	681	125	221	29.20	29.92	-.05	75.5	+5.4	99	1	84	58	11	67	29	66	61	64	2.25	-0.6	7	7,871	w.	39	nw.	17	19	9	3	3.3	0.0	0.0
Duluth	1,133	5	47	28.71	29.90	-.05	68.5	+4.6	94	28	79	48	5	58	32	60	56	70	2.73	-1.0	10	7,376	nw.	36	w.	19	13	13	5	4.6	0.0	0.0
North Dakota							71.1	+2.6										60	3.09	+0.4										4.2		
Moorhead	940	50	58	28.87	29.86	-.08	72.5	+4.4	105	25	85	50	8	60	37	62	56	62	5.19	+1.8	14	5,314	s.	25	s.	14	10	14	7	4.9	0.0	0.0
Bismarck	1,674	8	57	28.12	29.86	-.07	71.6	+1.8	107	27	84	47	5	59	40	60	53	60	3.39	+1.2	11	5,959	nw.	32	sw.	18	18	8	5	3.5	0.0	0.0
Devils Lake	1,478	11	44	28.32	29.86	-.07	69.3	+1.9	105	25	82	46	5	57	41	60	54	65	3.01	+0.4	7	5,692	nw.	24	n.	18	13	10	8	4.8	0.0	0.0
Ellendale	1,457	10	56	28.35	29.89	------	72.4	------	108	25	87	46	5	58	47	----	----	----	2.03	-1.1	9	8,637	nw.	40	n.	27	13	14	4	4.3	0.0	0.0
Grand Forks	833	12	67	------	------	------	71.0	------	103	25	84	47	8	58	41	61	----	----	2.38	------	8	------	nw.	50	sw.	19	19	8	4	----	0.0	0.0
Williston	1,878	41	48	27.93	29.86	-.06	71.0	+2.1	105	25	84	46	1	58	40	58	49	52	1.83	-0.1	11	5,512	nw.	30	w.	6	19	8	4	3.4	0.0	0.0
Upper Mississippi Valley							78.8	+3.8										60	2.47	-1.1										3.7		
Minneapolis	918	102	208	28.92	29.88	------	76.8	+4.5	104	27	87	57	9	67	28	----	----	----	1.12	-2.6	8	7,063	s.	29	n.	28	11	12	8	4.6	0.0	0.0
St. Paul	837	114	149	29.00	29.88	-.07	76.2	+4.1	102	27	88	52	9	64	33	----	----	----	1.54	-2.0	8	5,726	sw.	30	nw.	8	14	10	7	3.8	0.0	0.0
La Crosse	714	11	48	29.14	29.89	-.07	76.6	+3.8	101	16	89	52	11	64	37	65	60	64	1.84	-2.1	6	2,487	s.	15	nw.	19	16	12	3	3.6	0.0	0.0
Madison	974	70	78	28.90	29.91	-.06	75.8	+3.7	97	17	86	56	11	66	28	65	59	58	2.10	-1.8	8	4,692	sw.	22	w.	19	19	8	4	3.2	0.0	0.0
Wausau	1,247	4	62	28.62	29.92	------	72.6	------	98	27	85	46	10	60	37	----	----	----	2.11	-2.2	10	3,570	n.	24	nw.	9	18	8	5	3.6	0.0	0.0
Charles City	1,015	10	51	28.86	29.91	-.05	76.8	+4.5	99	31	90	51	10	63	30	65	58	55	1.15	-2.6	7	3,792	se.	20	w.	1	19	9	3	2.8	0.0	0.0
Davenport	606	71	79	29.27	29.91	-.06	80.2	+4.9	102	30	91	59	10	69	33	68	61	55	2.05	-1.3	6	5,033	sw.	28	sw.	1	14	14	3	3.9	0.0	0.0
Des Moines	861	5	99	29.02	29.90	-.06	78.6	+3.2	107	28	90	56	8	68	29	68	62	61	3.60	+0.1	8	5,292	s.	32	w.	1	15	9	7	4.1	0.0	0.0
Dubuque	700	81	96	29.18	29.90	-.07	78.1	+4.0	100	1	89	53	10	67	32	66	60	58	2.57	-1.4	9	3,430	s.	17	nw.	19	18	9	4	3.3	0.0	0.0
Keokuk	614	64	78	29.27	29.93	-.05	80.5	+3.6	104	29	91	59	10	70	28	60	64	60	1.71	-1.7	8	3,586	sw.	17	nw.	19	17	8	6	3.7	0.0	0.0
Cairo	358	87	93	29.56	29.93	-.07	80.9	+1.3	100	1	90	66	25	72	26	72	68	70	1.97	-1.1	11	3,824	s.	20	ne.	1	12	11	8	5.2	0.0	0.0
Peoria	609	11	45	29.28	29.94	-.04	79.2	+3.8	102	30	91	56	10	68	28	70	66	68	5.91	+2.3	6	2,724	sw.	15	n.	9	19	10	2	3.1	0.0	0.0
Springfield, Ill	636	5	191	29.26	29.92	-.06	81.2	+4.7	102	1	92	60	11	70	28	69	62	58	2.78	-0.1	3	6,511	sw.	38	n.	19	13	15	3	3.8	0.0	0.0
Hannibal	534	74	109	29.36	29.92	-.06	80.4	+3.6	101	29	91	58	6	70	29	----	----	----	2.63	-0.5	10	4,446	sw.	22	se.	22	16	10	5	3.0	0.0	0.0
St. Louis	568	265	303	29.34	29.92	-.07	82.2	+3.1	104	1	92	66	6	72	28	69	63	57	4.06	+1.1	8	6,358	s.	40	sw.	22	19	9	3	3.3	0.0	0.0
Missouri Valley							79.5	+3.6										54	2.40	-1.2										3.4		
Columbia, Mo	784	6	84	29.11	29.92	-.06	81.0	+4.1	102	29	92	57	6	70	30	----	----	----	2.53	-1.0	8	3,854	s.	23	w.	4	17	11	3	3.5	0.0	0.0
Kansas City	963	161	181	28.90	29.90	-.07	81.7	+3.6	102	28	92	62	5	72	28	69	62	57	3.24	-0.9	9	4,947	se.	39	sw.	4	18	10	3	3.3	0.0	0.0
St. Joseph	967	11	49	28.89	29.88	------	80.6	------	103	28	92	57	8	69	31	69	64	61	4.05	+0.4	8	4,388	sw.	40	w.	12	17	11	3	2.9	0.0	0.0
Springfield, Mo	1,324	98	104	28.58	29.95	-.03	79.3	+2.5	98	1	89	61	6	70	27	69	64	63	4.08	-0.1	10	5,225	s.	31	ne.	23	20	10	1	2.5	0.0	0.0
Iola	984	11	50	28.89	29.90	-.07	81.2	+3.0	101	28	93	55	6	69	36	----	----	----	1.16	-2.6	9	3,422	s.	21	nw.	4	14	13	4	4.0	0.0	0.0
Topeka	987	92	107	------	------	------	80.7	+2.9	103	28	92	60	5	70	31	----	----	----	3.41	-0.9	9	5,394	s.	34	nw.	22	17	9	5	3.2	0.0	0.0
Lincoln	1,189	11	81	28.65	29.87	-.08	79.4	+2.9	105	28	91	54	5	68	33	67	60	58	2.04	-1.8	6	5,830	s.	32	nw.	1	14	9	8	4.4	0.0	0.0
Omaha	1,105	115	122	28.74	29.89	-.06	80.4	+3.7	105	28	90	57	5	70	27	66	59	53	2.10	-1.4	6	4,134	s.	22	nw.	8	20	7	4	2.9	0.0	0.0
Valentine	2,598	47	54	27.25	29.90	-.03	76.3	+2.6	106	27	90	48	5	63	41	62	53	51	4.02	+1.0	8	6,825	s.	33	w.	8	18	9	4	3.6	0.0	0.0
Sioux City	1,135	94	164	28.69	29.86	-.09	78.4	+4.1	99	30	89	53	9	67	31	65	58	54	1.74	-1.8	5	7,626	s.	36	n.	11	16	9	6	4.0	0.0	0.0
Huron	1,306	59	74	28.51	29.87	-.07	77.2	+5.4	106	15	92	49	5	63	38	63	54	49	1.38	-1.8	7	6,762	s.	28	nw.	6	21	8	2	2.9	0.0	0.0
Pierre	1,572	70	75	28.21	29.83	-.10	79.6	+4.3	112	15	94	52	5	66	44	62	51	43	0.71	-2.0	8	7,117	se.	46	ne.	30	16	14	1	3.5	0.0	0.0
Yankton	1,233	40	57	28.60	29.88	-.06	78.8	+4.6	103	28	91	54	9	67	36	----	----	----	0.75	-2.6	4	4,819	s.	29	sw.	14	15	11	5	3.7	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, July, 1931*—Continued

District and station	Elevation of instruments			Pressure			Temperature of the air									Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation			Wind					Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range				Total	Departure from normal	Days with 0.01 or more	Total movement	Prevailing direction	Maximum velocity: Miles per hour	Maximum velocity: Direction	Maximum velocity: Date						
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Northern Slope							71.0	+3.2										47	1.40	-0.2										3.8		
Billings	3,140	5					71.6		107	21	91	38	4	53	58				0.58		6		nw.				13	11	7		0.0	0.0
Havre	2,505	11	44	27.33	29.92	+0.01	69.4	+1.1	103	21	83	43	4	56	45	55	43	50	3.25	+1.4	8	5,200	nw.	32	n.	27	18	7	6	3.6	0.0	0.0
Helena	4,124	89	113	25.81	29.90	-.03	69.6	+3.9	102	21	84	38	5	56	40	53	40	42	1.29	+0.2	6	5,358	sw.	30	n.	6	15	11	5	4.1	T.	0.0
Kalispell	2,973	48	56	26.92	29.91	-.02	67.2	+3.1	97	25	82	42	7	52	43	52	40	46	0.70	-0.4	7	4,176	nw.	35	sw.	9	16	7	8	4.0	0.0	0.0
Miles City	2,371	48	55	27.40	29.90	-.02	75.2	+2.3	107	23	89	48	8	62	43	59	48	47	0.77	-0.8	6	4,285	ne.	32	nw.	10	16	11	4	3.8	0.0	0.0
Rapid City	3,259	50	58	26.58	29.90	-.03	75.0	+4.0	105	25	88	46	7	62	41	59	48	46	1.42	-1.0	11	5,260	n.	40	nw.	5	15	14	2	3.6	0.0	0.0
Cheyenne	6,088	84	101	24.09	29.89	-.03	70.0	+3.3	95	25	84	40	6	56	40	54	43	46	0.75		8	6,936	w.	34	w.	3	12	13	6	4.2	0.0	0.0
Lander	5,372	60	68	24.68	29.87	-.05	71.7	+4.3	100	21	88	40	7	55	44	54	42	43	2.10	+1.4	8	3,415	sw.	31	sw.	10	20	9	2	2.8	0.0	0.0
Sheridan	3,790	10	47	26.09	29.90		71.6		103	27	89	40	7	54	54	56	46	51	1.43	+0.2	8	2,691	nw.	30	nw.	5	16	12	3	3.8	0.0	0.0
Yellowstone Park	6,241	11	48	23.97	29.94	+.02	63.6	+2.1	92	21	80	33	6	48	42	49	38	49	0.72	-0.6	9	4,873	sw.	30	n.	5	14	12	5	4.0	0.0	0.0
North Platte	2,821	11	51	27.03	29.87	-.06	77.6	+4.7	103	22	91	48	5	64	44	63	55	52	0.97	-1.8	8	4,478	se.	29	ne.	12	15	13	3	3.6	0.0	0.0
Middle Slope							79.8	+2.6										52	1.39	-1.4										3.4		
Denver	5,292	106	113	24.77	29.89	-.02	76.0	+3.8	100	22	89	49	6	63	37	57	45	40	0.90	-0.8	6	4,530	s.	26	nw.	16	12	17	2	4.0	0.0	0.0
Pueblo	4,685	80	86	25.31	29.86	-.05	77.2	+3.0	103	22	92	47	5	62	46	58	46	42	0.86	-1.1	8	4,153	e.	32	nw.	15	19	10	2	3.8	0.0	0.0
Concordia	1,392	50	58	28.47	29.89	-.06	81.1	+3.1	109	27	93	54	5	69	34	67	60	56	3.04	-0.7	4	4,815	s.	20	s.	11	19	9	3	3.1	0.0	0.0
Dodge City	2,509	88	100	27.38	29.90	-.03	79.6	+1.2	104	22	92	51	5	67	36	65	57	55	2.00	-1.1	10	8,106	s	34	sw.	31	22	7	2	2.6	0.0	0.0
Wichita	1,358	139	158	28.49	29.88	-.06	81.6	+2.2	101	27	92	60	5	71	31	68	62	57	0.97	-2.4	5	7,922	s.	36	n.	4	13	16	2	3.6	0.0	0.0
Oklahoma City	1,214	10	47	28.64	29.88	-.06	83.4	+2.8	104	4	95	61	6	72	36	70	64	59	0.55	-2.3	3	5,645	s.	23	nw.	8	18	9	4	3.5	0.0	0.0
Southern Slope							81.2	0.0										59	1.60	-0.8										3.6		
Abilene	1,738	10	52	28.13	29.88	-.05	83.6	+0.8	101	7	95	65	6	72	34	69	62	57	2.21	+0.1	6	5,746	s.	27	e.	8	14	13	4	4.2	0.0	0.0
Amarillo	3,676	10	49	26.27	29.90	-.02	79.4	+2.6	101	23	92	57	5	66	36	64	57	55	1.40	-1.4	9	5,805	s.	31	s.	12	20	9	2	2.9	0.0	0.0
Del Rio	944	64	71	28.88	29.84	-.06	82.7	-3.6	96	7	92	67	10	73	25	73	69	70	1.84	-0.6	5	5,482	se.	34	e.	10	11	16	4	4.5	0.0	0.0
Roswell	3,566	75	85	26.35	29.86	-.02	79.0	+0.1	99	6	92	59	6	66	40	64	56	54	0.98	-1.3	8	4,856	se.	25	se.	20	21	9	1	2.6	0.0	0.0
Southern Plateau							82.8	+3.9										47	0.39	-0.8										2.9		
El Paso	3,778	152	175	26.13	29.79	-.05	83.2	+2.1	102	16	94	65	6	72	32	65	55	44	0.73	-1.3	7	5,066	e.	34	ne.	17	19	11	1	3.0	0.0	0.0
Albuquerque	4,972	51	66	25.06	29.79		77.7		99	23	91	58	6	64	37	61	52	50	0.69		4	3,819	sw.	28	se.	20	14	13	4	4.1	0.0	0.0
Santa Fe	7,013	38	53	23.35	29.84	-.04	70.2	+1.2	90	22	82	48	5	58	31	55	46	50	1.00	-1.4	15	3,652	se.	20	n.	25	8	19	4	4.8	0.0	0.0
Flagstaff	6,907	10	59	23.43	29.81	-.02	68.6	+3.6	92	25	84	42	6	53	44	55		59	2.71		13	4,572	nw.	31	nw.	11	2	20	9		0.0	0.0
Phoenix	1,108	10	107	28.58	29.68	-.10	95.2	+5.4	114	24	108	77	31	83	30	71	59	35	0.02	-1.0	2	4,113	w.	34	e.	11	28	3	0	1.7	0.0	0.0
Yuma	141	9	54	29.55	29.69	-.07	95.0	+4.2	116	2	108	73	22	81	36	75	66	45	0.21	0.0	3	3,660	sw.	35	e.	21	28	3	0	1.1	0.0	0.0
Independence	3,957	6	27	25.89	29.82	-.01	84.7	+6.6	106	19	101	58	15	69	40	57			0.00	-0.1	0		nw.				21	4	6		0.0	0.0
Middle Plateau							78.5	+6.1										28	0.41	-0.1										2.2		
Reno	4,532	74	81	25.44	29.82	-.05	77.4	+9.9	106	20	95	50	1	60	43	54	36	28	T.	-0.2	0	4,589	w.	30	w.	15	26	5	0	1.4	0.0	0.0
Tonopah	6,090	12	20				78.6		98	19	92	52	4	66	36	55	37	25	0.10		1		nw.								0.0	0.0
Winnemucca	4,344	18	56	25.58	29.85	-.05	77.2	+6.6	108	20	96	42	1	58	53	53	33	24	0.12	-0.1	1	4,291	sw.	31	s.	24	23	8	0	1.6	0.0	0.0
Modena	5,473	10	43	24.62	29.79	-.07	76.3	+5.7	101	26	93	42	5	59	51	54	36	31	0.52	-0.6	3	6,800	w.	36	sw.	14	16	12	3	3.6	0.0	0.0
Salt Lake City	4,360	163	203	25.58	29.82	-.08	80.8	+5.1	105	24	93	55	5	68	36	57	39	26	0.61	+0.1	3	5,025	nw.	32	s.	29	25	4	2	1.7	0.0	0.0
Grand Junction	4,602	60	68	25.34	29.82	-.07	80.9	+3.2	104	23	96	55	3	66	39	57	41	32	0.74	+0.1	4	4,045	se.	37	s.	27	21	7	3	2.8	0.0	0.0
Northern Plateau							75.1	+4.1										33	0.12	-0.4										2.2		
Baker	3,471	48	53	26.43	29.93	-.02	70.0	+4.4	102	20	86	41	1	54	47	52	38	35	0.07	-0.5	1	3,743	n.	24	nw.	5	22	8	1	2.4	0.0	0.0
Boise	2,739	79	87	27.08	29.86	-.07	77.4	+4.5	108	20	94	47	6	61	43	56	41	32	T.	-0.2	0	3,057	nw.	22	n.	5	24	3	4	2.2	0.0	0.0
Lewiston	757	40	48	29.11	29.90	-.05	77.8	+3.8	114	20	95	49	1	61	53				0.02	-0.5	1	2,436	e.	21	nw.	10	22	7	2	2.5	0.0	0.0
Pocatello	4,477	60	68	25.46	29.84	-.08	75.8	+5.0	105	21	91	46	7	60	42	53	35	30	0.62	-0.2	4	4,876	se.	30	sw.	24	21	5	5	2.9	0.0	0.0
Spokane	1,929	101	110	27.91	29.91	-.05	72.8	+3.8	106	20	87	44	1	58	48	54	38	36	T.	-0.7	0	3,602	s.	21	sw.	10	22	7	2	2.1	0.0	0.0
Walla Walla	991	57	65	28.84	29.90	-.07	76.9	+2.9	105	20	92	49	1	62	40	57	39	31	0.11	-0.3	2	2,754	w.	14	w.	10	23	8	0	1.8	0.0	0.0
Yakima	1,076	58	67	28.79	29.92		75.9	+4.5	103	20	91	52	14	61	39	56	40	34	T.	-0.3	0	4,352	nw.	20	nw.	2	23	7	1	1.5	0.0	0.0
North Pacific Coast Region							64.1	+2.0										66	0.04	-0.6										3.4		
North Head	211	11	56	29.83	30.06	-.02	58.1	+0.9	85	7	62	47	19	54	31	55	53	85	0.00	-0.9	3	9,934	n.	34	n.	4	9	10	12	5.6	0.0	0.0
Port Angeles	29	8	53		30.06		60.4		86	6	60	44	27	52	32				0.14	-0.3	2	4,811	sw.	25	nw.	4	20	7	4		0.0	0.0
Seattle	125	215	250	29.88	30.01	-.03	65.2	+2.1	90	8	74	52	1	56	28	57	52	65	0.11	-0.5	3	4,593	ne.	28	sw.	20	19	7	5	3.1	0.0	0.0
Tacoma	194	172	201	29.83	30.03	-.03	64.8	+2.0	88	8	74	48	1	55	28				T.	-0.6	0	4,830	n.	30	sw.	20	16	11	4	3.6	0.0	0.0
Tatoosh Island	86	9	53	29.95	30.04	-.01	56.6	+1.5	76	7	61	47	31	52	24	54	53	90	0.30	-1.2	4	6,881	sw.	36	s.	20	6	11	14	6.4	0.0	0.0
Medford	1,329	29	58	28.51	29.88		74.3		105	19	93	48	3	56	48	57	44	44	0.00	-0.4	0	4,080	nw.	24	nw.	20	27	4	0	0.9	0.0	0.0
Portland, Oreg	153	68	106	29.83	29.98	-.07	70.1	+3.4	101	19	82	53	27	58	36	59	52	58	T.	-0.6	0	4,236	nw.	18	nw.	5	20	7	4	3.0	0.0	0.0
Roseburg	510	75	99	29.42	29.96	-.07	69.6	+2.2	102	19	84	48	1	55	46	58	49	57	0.00	-0.3	0	3,281	n.	22	n.	3	25	6	0	1.5	0.0	0.0
Middle Pacific Coast Region							71.2	+4.2										58	T.	0.0										1.9		
Eureka	62	73	80	29.90	29.97	-.08	56.6	+1.1	76	4	61	48	27	52	24	53	51	85	0.01	-0.1	1	4,445	nw.	27	n.	2	13	13	5	4.3	0.0	0.0
Red Bluff	330	5	58	29.41	29.75	-.14	87.0	+6.2	114	19	104	50	16	70	45	62	43	27	0.00	0.0	0	3,671	s.	22	nw.	3	30	1	0	0.5	0.0	0.0
Sacramento	69	106	117	29.69	29.76	-.12	79.5	+6.3	109	4	98	52	16	61	47	62	50	46	T.	0.0	0	5,717	s.	18	sw.	14	30	1	0	0.6	0.0	0.0
San Francisco	155	208	243	29.68	29.84	-.11	62.3	+3.8	99	3	70	51	31	55	37	55	52	75	T.	0.0	0	5,470	sw.	25	nw.	14	18	12	1	2.8	0.0	0.0
San Jose	141	12	110	29.70	29.85		70.7	+3.8	106	3	85	50	16	56	46				0.00	0.0	0	3,815	nw.	18	nw.	1	27	3	1	1.3	0.0	0.0
South Pacific Coast Region							79.5	+6.3										59	T.	0.0										2.5		
Fresno	327	89	98	29.40	29.74	-.09	87.6	+5.5	113	26	105	60	16	71	39	62	42	26	T.	0.0	0	5,183	nw.	20	nw.	14	28	3	0	0.8	0.0	0.0
Los Angeles	338	159	191	29.46	29.81	-.09	77.2	+7.0	94	26	86	64	5	68	26	68	64	72	0.00	0.0	0	2,949	sw.	16	w.	25	25	5	1	2.4	0.0	0.0
San Diego	87	62	70	29.72	29.81	-.11	73.6	+6.4	85	26	78	62	1	69	18	68	66	80	T.	0.0	0	3,714	sw.	16	s.	9	11	17	3	4.4	0.0	0.0
West Indies																																
San Juan, P. R	82	9	54	29.88	29.96		81.5	+1.4	90	2	86	74	24	77	14				9.56	+3.6	20	6,092	e.	41	ne.	24	2	22	7	6.1	0.0	0.0
Panama Canal																																
Balboa Heights	118	6	97		[1] 29.83	+.01	79.4	-0.9	87	15	84	72	14	74	15			[1] 88	10.46	+3.2	26	3,466	s.	20	sw.	20	0	9	22	8.2	0.0	0.0
Cristobal	36	6	97		[1] 29.82	-.02	81.6	+1.2	91	9	88	74	20	76	15	76	75	[1] 83	13.36	-2.3	25	4,125	se.	24	sw.	16	0	7	24	8.6	0.0	0.0
Alaska																																
Fairbanks	455	11	44	[2] 29.37	[2] 29.87		58.4		80	1	68	40	11	48	32	52	47	70	1.43		17	2,812	w.	20	sw.	5	3	9	19	7.4	0.0	0.0
Juneau	80	11	50	[2] 29.96	[2] 30.05		55.1		78	3	61	46	3	49	31	52	49	82	5.71		22	3,321	s.	23	se.	21	5	5	21	7.7	0.0	0.0
Hawaiian Islands																																
Honolulu	38	86	100	[2] 29.97	[2] 30.01		77.8	+0.1	84	1	82	70	7	73	12	70	67	70	0.52	-0.7	15	6,457	e.	24	ne.	21	18	11	2	3.5	0.0	0.0

[1] Observations taken bihourly.

[2] Pressure not reduced to mean of 24 hours.

TABLE 2.—*Data furnished by the Canadian Meteorological Service, late reports, June, 1931*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max.+mean min. ÷2	Temperature of the air: Departure from normal	Temperature of the air: Mean maximum	Temperature of the air: Mean minimum	Temperature of the air: Highest	Temperature of the air: Lowest	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Total snowfall
	Feet	*Inches*	*Inches*	*Inches*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	*Inches*	*Inches*	*Inches*
Cape Race, N. F	99												
Sydney, C. B. I	48	29.90	29.95	0.00	56.3	+0.9	65.7	46.9	78	40	4.32	+1.09	0.0
Halifax, N. S	88	29.81	29.91	−.04	59.1	+1.4	68.1	50.2	88	44	6.30	+2.54	0.0
Yarmouth, N. S	65	29.79	29.86	−.09	58.0	+3.0	65.3	50.8	75	42	5.74	+2.81	0.0
Charlottetown, P. E. I	38	29.83	29.87	−.05	56.5	−0.9	64.0	49.1	81	42	3.32	+0.65	0.0
Chatham, N. B	28	29.83	29.86	−.03	57.8	−2.2	67.6	48.1	86	39	4.53	+1.07	0.0
Father Point, Que	20												
Quebec, Que	296	29.63	29.95	+.03	62.3	+1.1	72.0	52.6	86	45	7.72	+4.07	0.0
Doucet, Que	1,236				54.8		72.2	37.5	94	25	2.56		0.0
Montreal, Que	187	29.73	29.93	−.01	66.7	+1.8	75.9	57.5	89	49	3.81	+0.28	0.0
Ottawa, Ont	236	29.70	29.96	+.02	65.5	+0.2	76.5	54.5	94	44	1.75	−1.17	0.0
Kingston, Ont	285	29.67	29.98	+.01	63.9	+0.5	71.5	56.3	81	49	2.61	+0.18	0.0
Toronto, Ont	379	29.58	29.97	.00	65.9	+2.5	75.7	56.1	91	43	2.16	−0.64	0.0
Cochrane, Ont	930												
White River, Ont	1,244	28.64	29.93	−.01	60.2	+1.5	74.9	45.5	101	25	0.79	−1.43	0.0
London, Ont	808				65.1		77.1	53.1	96	38	3.14		0.0
Southampton, Ont	656	29.29	30.00	+.03	61.5	+1.1	72.0	51.0	90	35	1.83	−0.52	0.0
Parry Sound, Ont	688	29.31	29.99	+.03	62.9	+1.2	73.1	52.8	90	39	1.80	−0.62	0.0
Port Arthur, Ont	644	29.25	29.96	+.02	58.3	+1.9	67.5	49.1	90	37	2.34	−0.39	0.0
Winnipeg, Man	760	29.06	29.87	−.02	65.8	+3.6	77.4	54.3	97	34	1.13	−2.16	0.0
Minnedosa, Man	1,690	28.09	29.87	−.02	63.5	+3.9	77.6	49.5	108	27	1.78	−1.22	0.0
Le Pas, Man	860				59.4		70.5	48.4	92	37	1.48		0.0
Qu'Appelle, Sask	2,115	27.62	29.82	−.05	63.7	+3.8	77.9	49.4	100	31	1.54	−1.88	0.0
Moose Jaw, Sask	1,759				65.9		80.1	51.6	99	39	3.95		0.0
Swift Current, Sask	2,392	27.31	29.77	−.10	65.8	+5.8	80.8	50.9	102	36	2.45	−0.22	0.0
Medicine Hat, Alb	2,365	27.36	29.79	−.06	64.9	+2.9	78.2	51.6	94	36	2.13	−0.63	0.0
Calgary, Alb	3,428	26.25	29.87	+.03	57.2	+1.2	69.0	45.5	84	37	2.17	−0.28	0.0
Banff, Alb	4,521	25.32	29.82	−.02	52.4	+0.9	63.9	40.9	80	29	3.64	+0.31	0.0
Prince Albert, Sask	1,450	28.32	29.86	−.01	60.7	+3.0	72.6	48.9	96	35	2.83	+0.32	0.0
Battleford, Sask	1,592	28.10	29.81	−.05	60.9	+1.4	74.7	47.1	92	31	0.89	−2.42	0.0
Edmonton, Alb	2,150	27.54	29.78	−.06	57.4	+0.5	68.7	46.2	88	30	5.97	+3.11	0.0
Kamloops, B. C	1,262	28.59	29.86	−.01	63.2	−0.6	72.8	53.7	92	46	1.25	−0.17	0.0
Victoria, B. C	230	29.73	29.98	−.03	56.7	+0.4	63.3	50.2	80	47	4.33	+3.13	0.0
Estevan Point, B. C	20				52.4		59.2	45.7	72	40	7.05		0.0
Prince Rupert, B. C	170				54.3		61.9	46.8	74	40	1.77		0.0
Hamilton, Ber	151												

Chart I. Departure (°F.) of the Mean Temperature from the Normal, July, 1931

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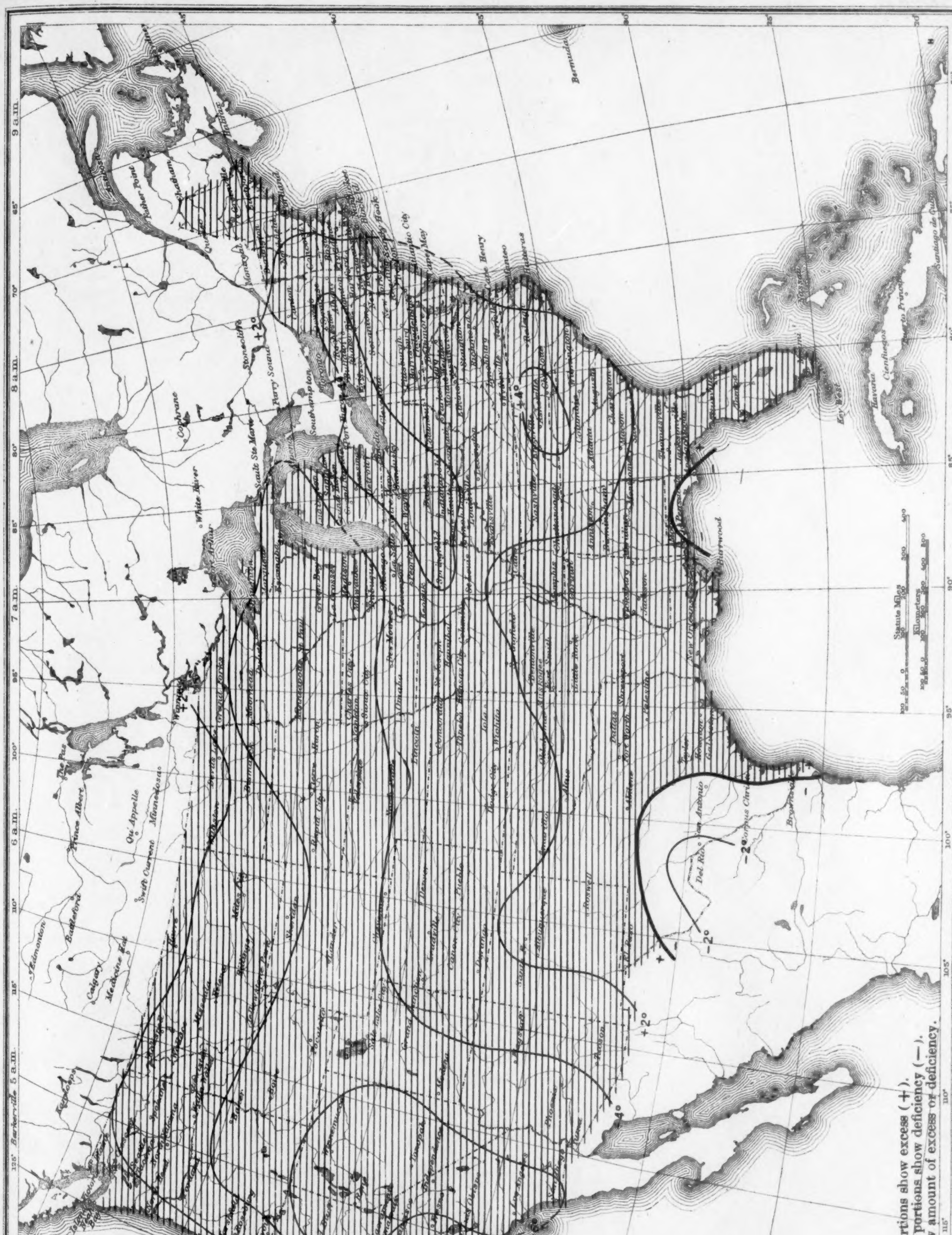
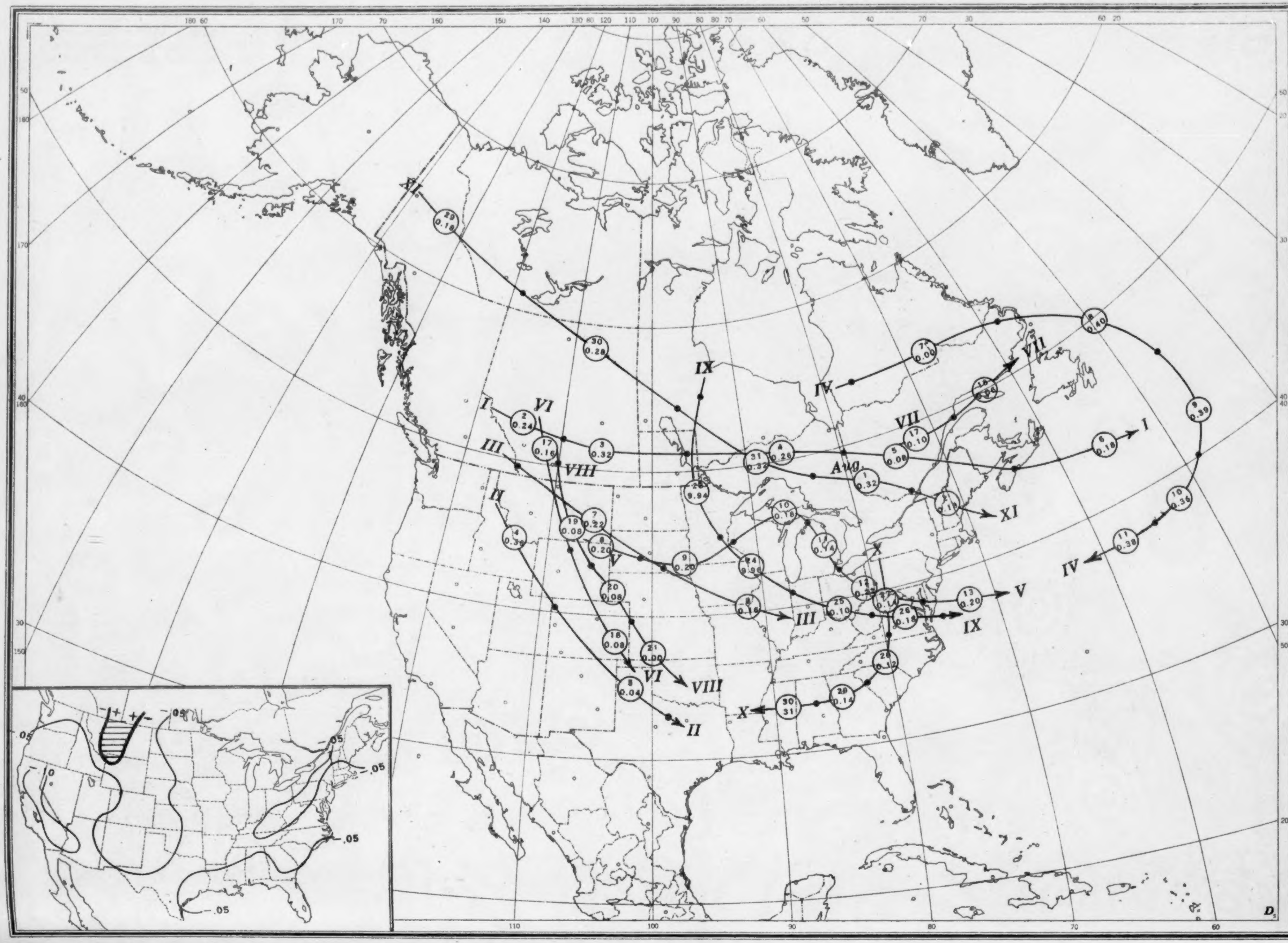


Shaded portions show excess (+).
Unshaded portions show deficiency (−).
Lines show amount of excess or deficiency.

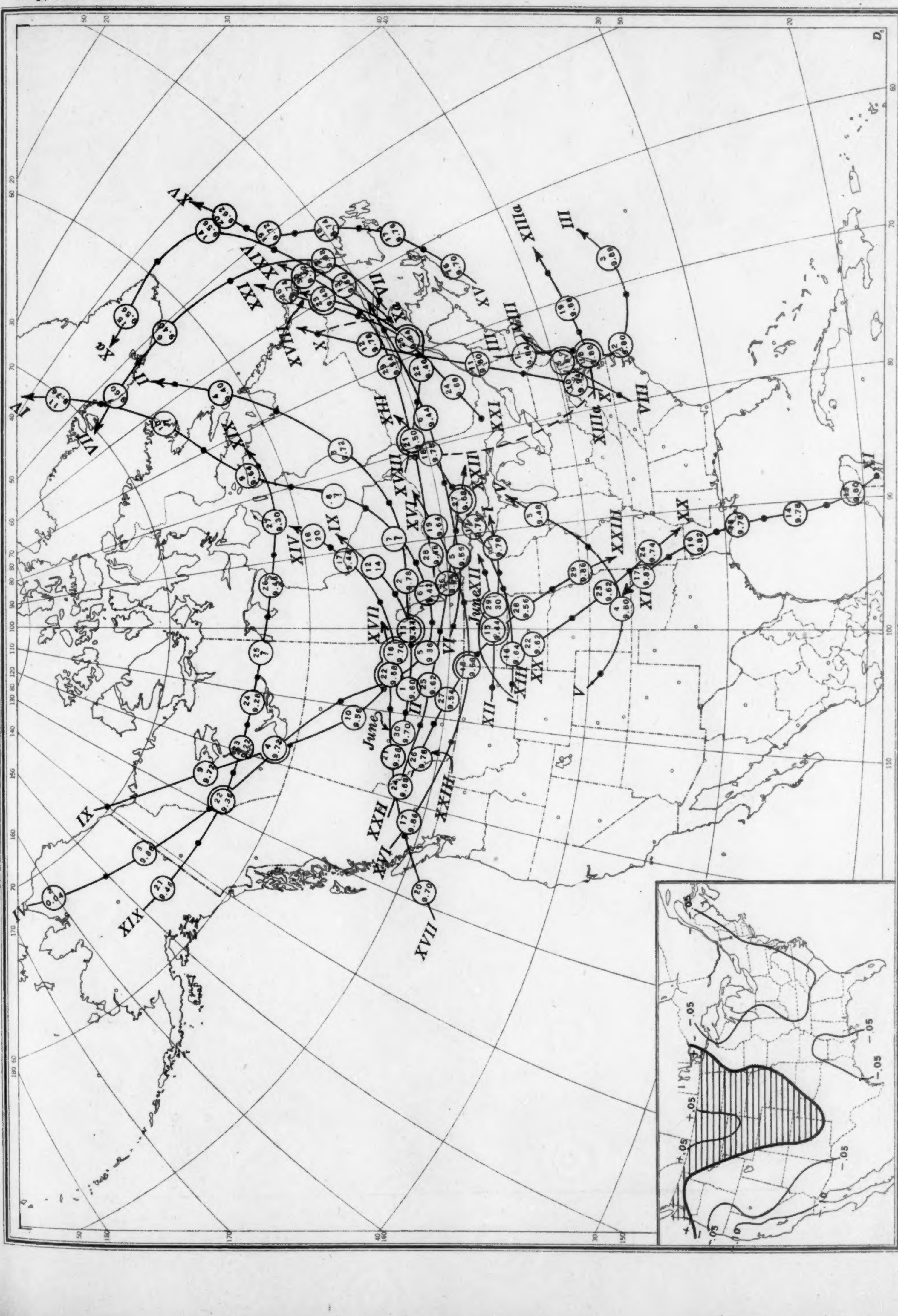
Chart II. Tracks of Centers of Anticyclones, July, 1931. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by Welby R. Stevens)



Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, July, 1931. (Inset) Change in Mean Pressure from Preceding Month
(Plotted by Welby R. Stevens)



Circle indicates position of cyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 8 p. m. (75th meridian time).

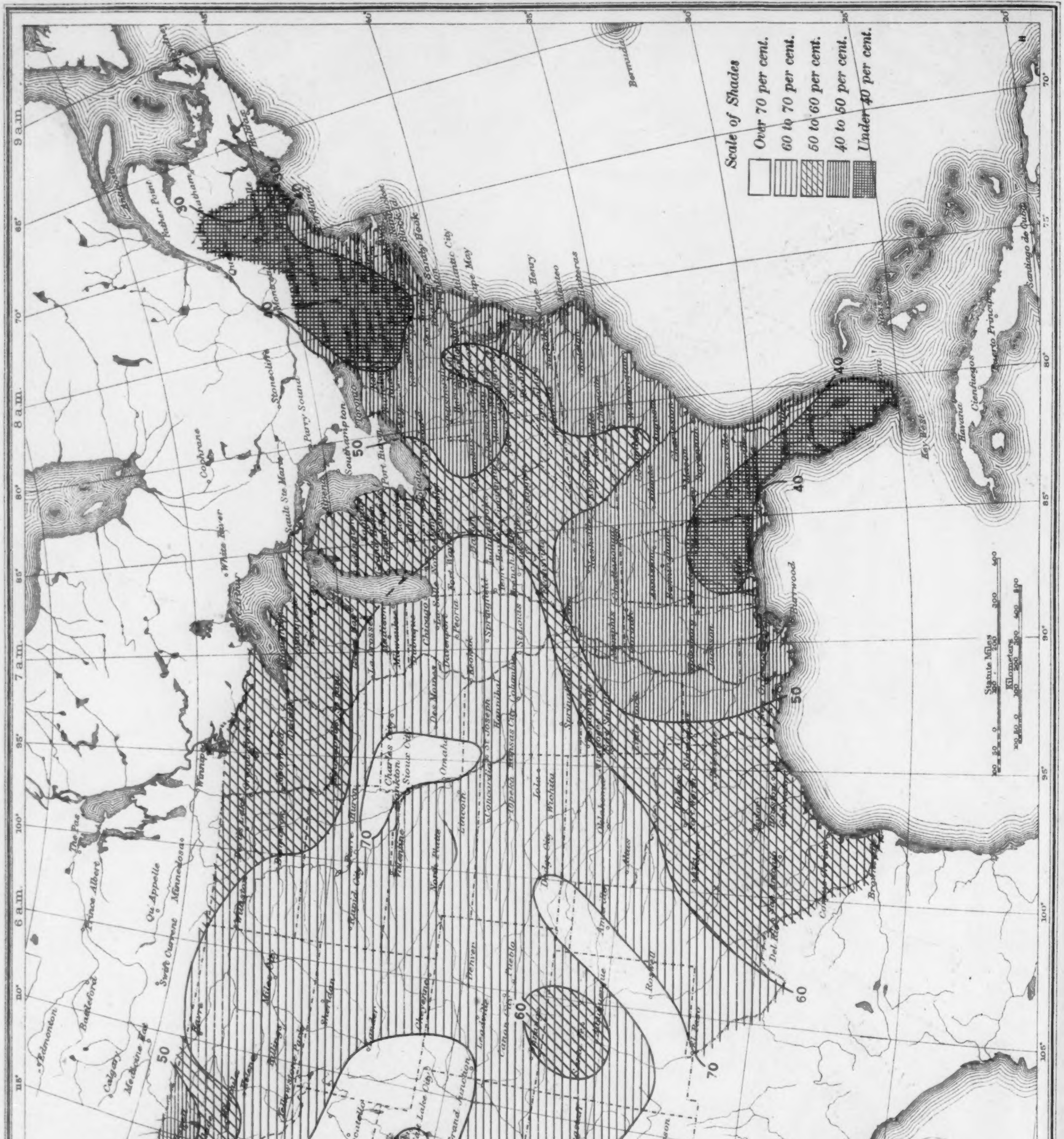
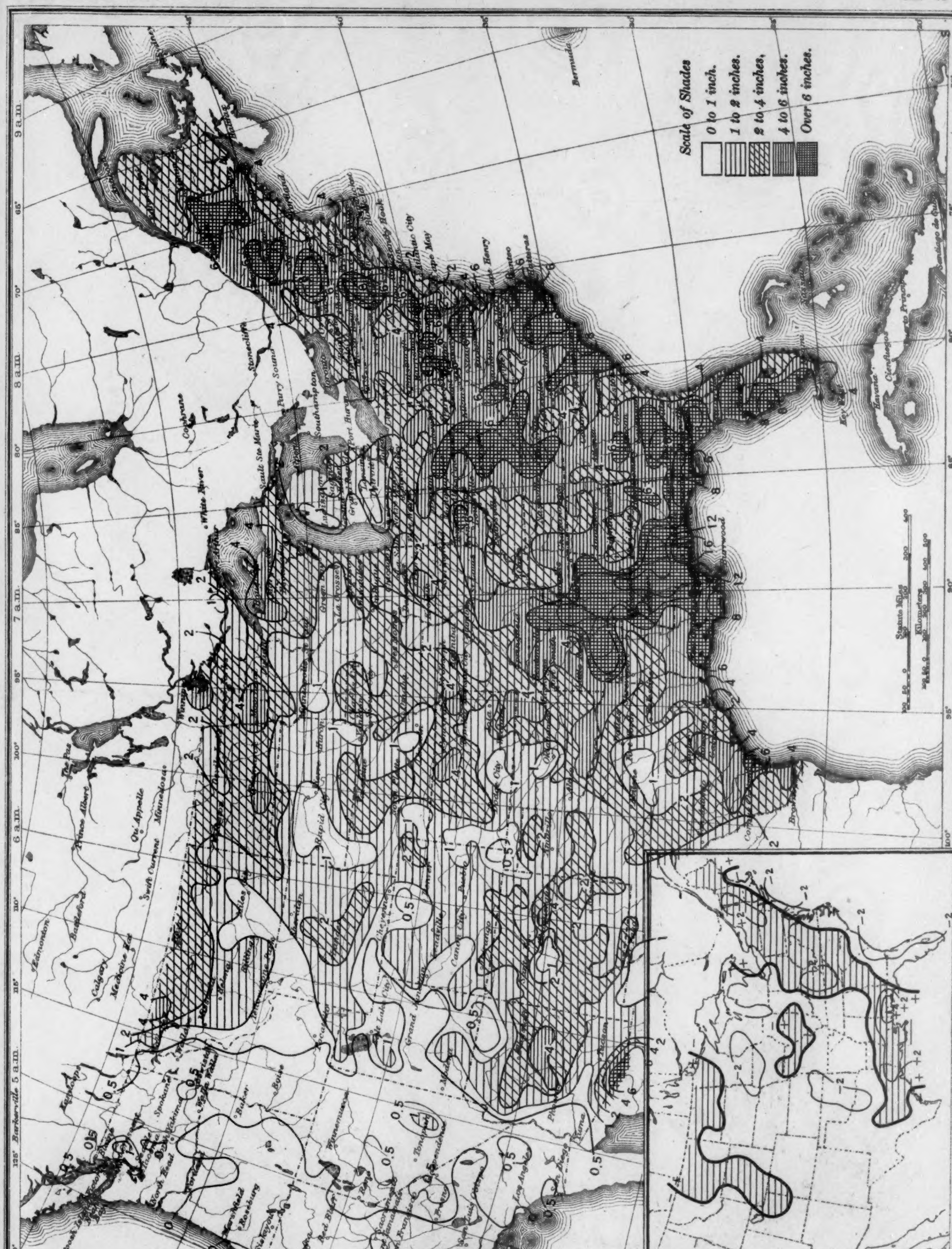


Chart IV. Percentage of Clear Sky between Sunrise and Sunset, July, 1931

Chart V. Total Precipitation, Inches, July, 1931. (Inset) Departure of Precipitation from Normal



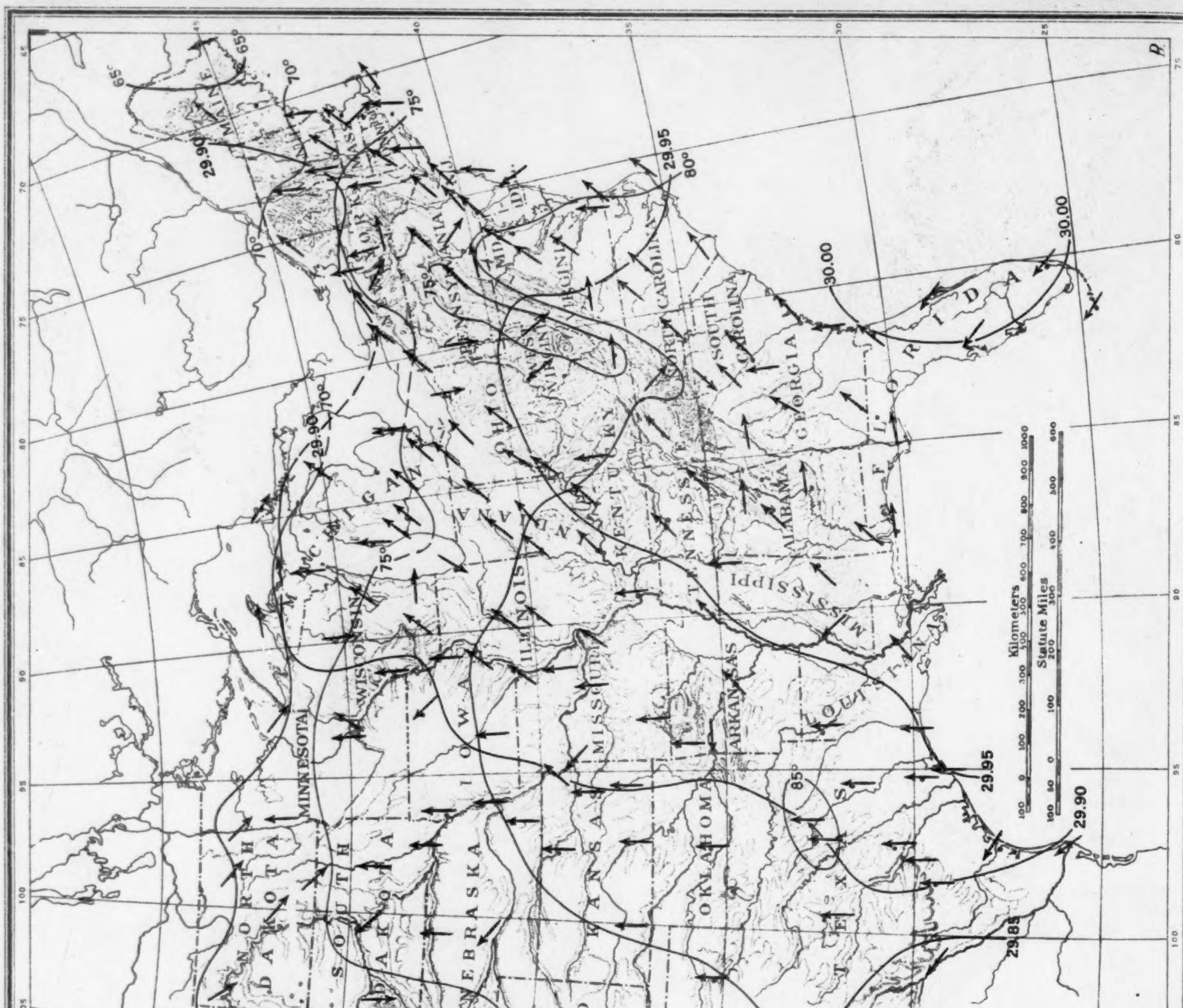


Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, July, 1931

Chart VIII. Weather Map of North Atlantic Ocean, July 15, 1931

(Plotted from the Weather Bureau Northern Hemisphere Chart)

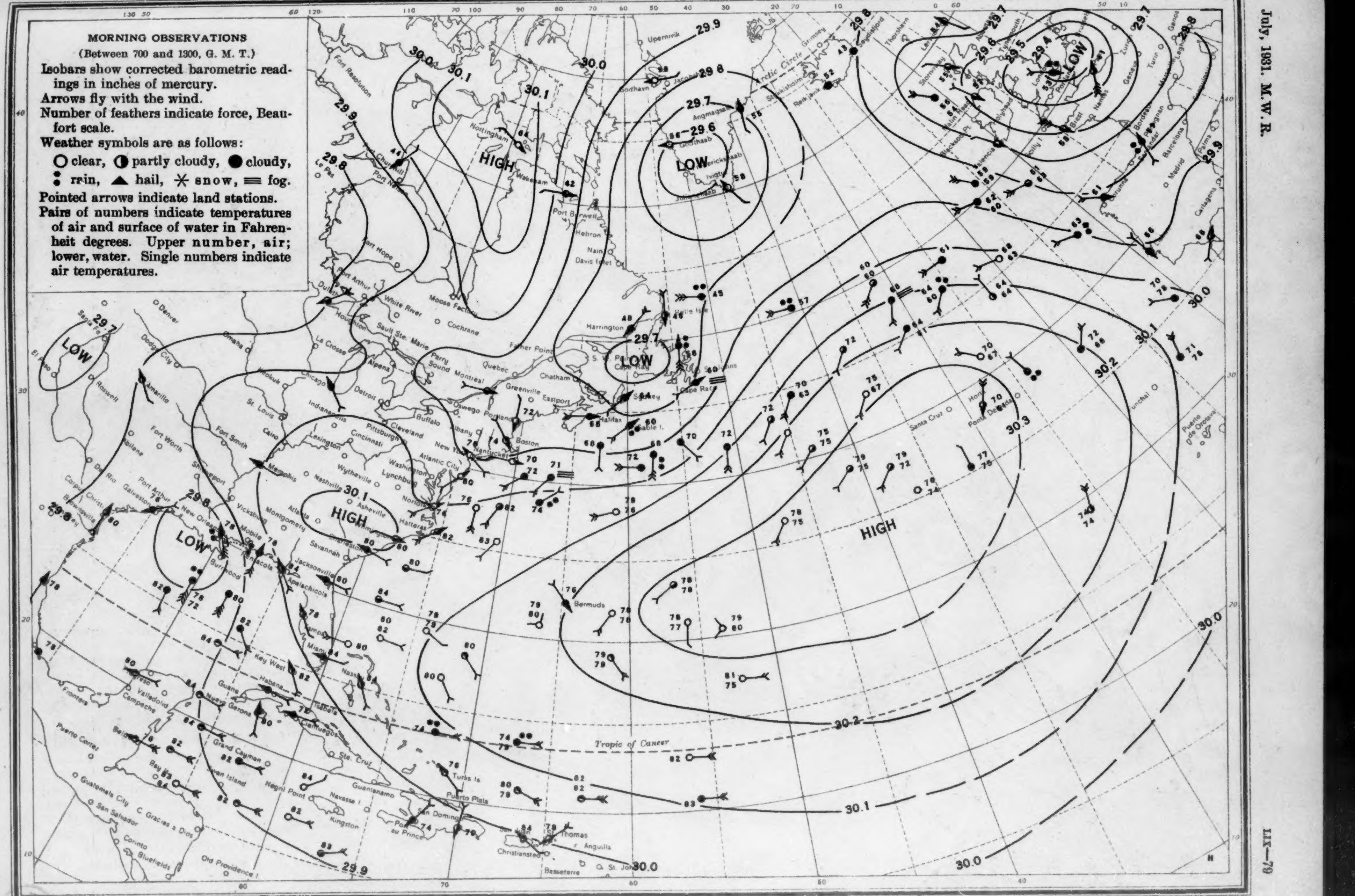


Chart IX. Weather Map of North Atlantic Ocean, July 16, 1931

(Plotted from the Weather Bureau Northern Hemisphere Chart)

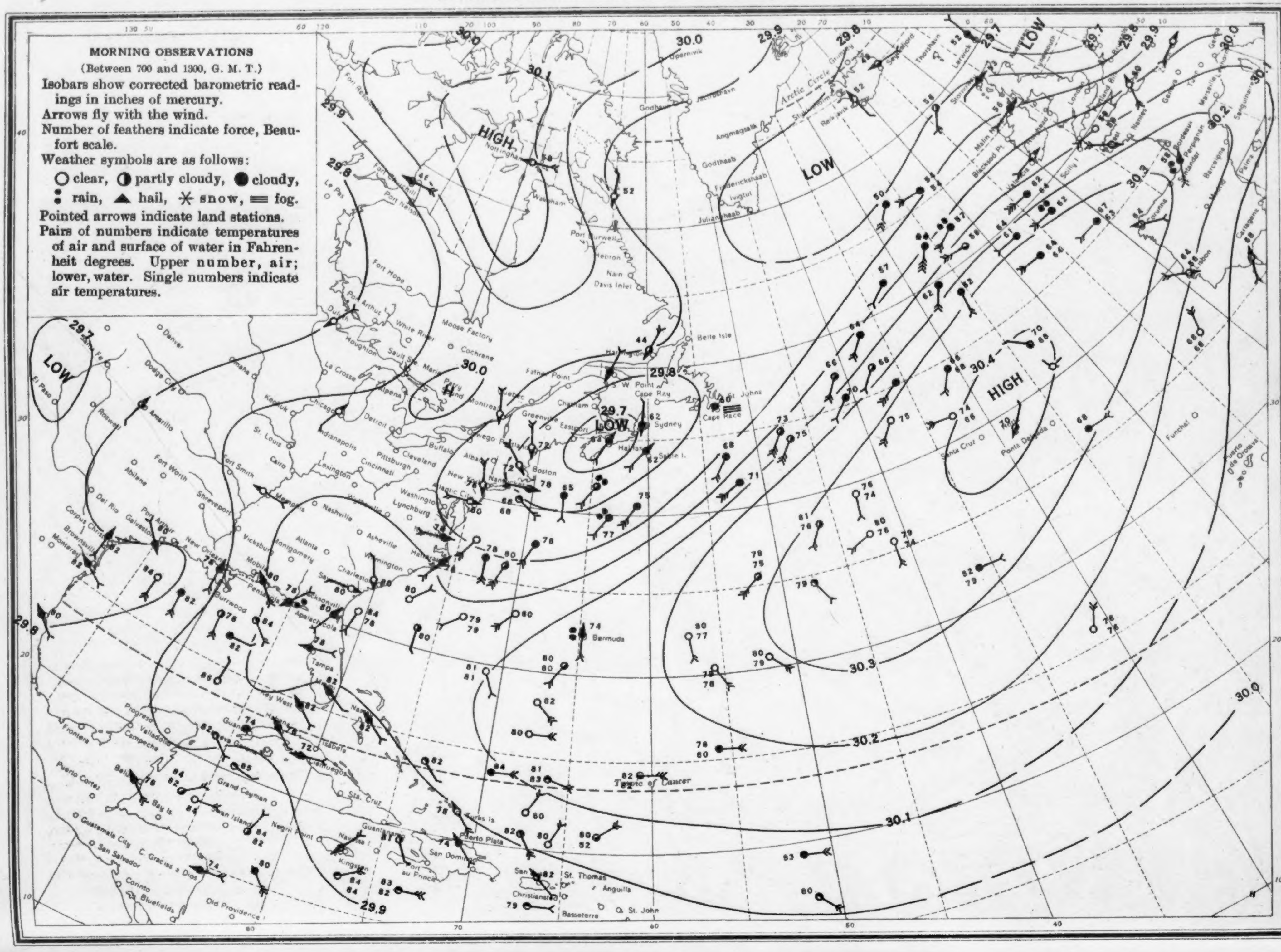


Chart X. Weather Map of North Atlantic Ocean, July 28, 1931

(Plotted from the Weather Bureau Northern Hemisphere Chart)

Chart X. Weather Map of North Atlantic Ocean, July 28, 1931

(Plotted from the Weather Bureau Northern Hemisphere Chart)

MORNING OBSERVATIONS

(Between 700 and 1300, G. M. T.)

Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
○ clear, ◑ partly cloudy, ● cloudy, ⁞ rain, ▲ hail, ✳ snow, ≡ fog.
Pointed arrows indicate land stations.
Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water. Single numbers indicate air temperatures.

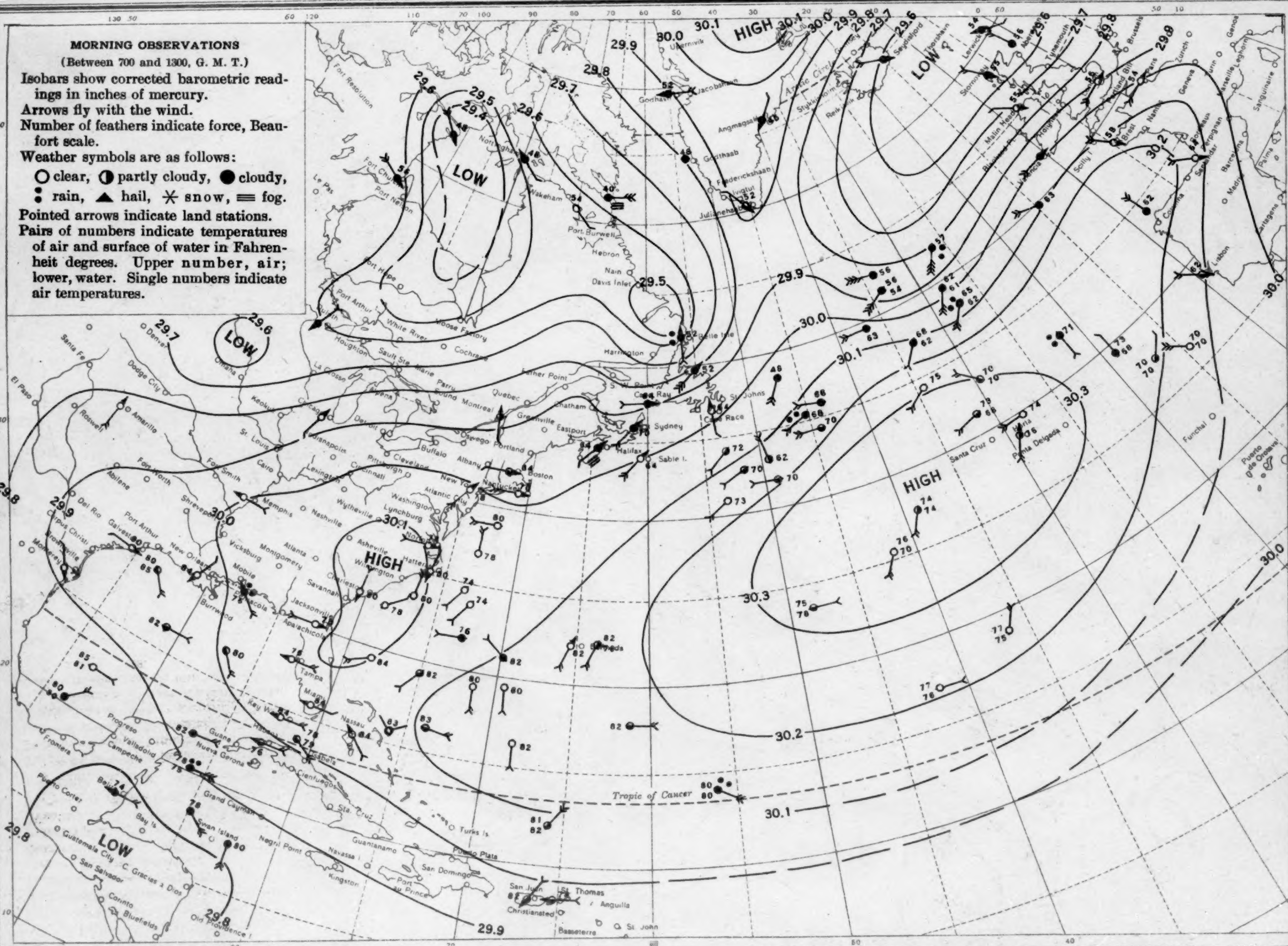


Chart XI. Weather Map of North Atlantic Ocean, July 29, 1931

(Plotted from the Weather Bureau Northern Hemisphere Chart)